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ON THE VENTILATION OF HALLS OF AUDIENCE.

BY ROBERT BRIGGS, MEMBER OF THE SOCIETY.

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It is not too great an admission to say that the Ventilation of Halls of Audience, that is, assembly rooms, lecture rooms, churches, theatres, and similar places, has not yet been generally effected in the most satisfactory manner.

All rooms, where many people are gathered together, are liable to be-

come more or less offensive after a brief duration of session, and noticeably more objectionable as the session lengthens.

The flippant writer who records and publishes the circumstances does not hesitate to ascribe the defect to "want of scientific knowledge," with the implication that either he himself possesses, or that he can readily produce the encyclopedia which contains such information. Those who have practically to do with the erection of buildings or the construction of apparatus for ventilating and warming the same, and especially those in whose charge the finished buildings and their apparatus are placed, are well aware that the teachings of the books or the records of practice have not gone beyond the studies of requirements, most frequently under conditions not applicable to our climate of the northern United States; or further than an incomplete description of the details of apparatus, which certainly have been evolved in a very perfect way in the workshop. In this regard of apparatus as a whole, it may be averred at once, that for more than twenty years the practice of American contractors has been such as will meet every requirement of supply of air in any quantity and at any temperature desired.

The literature of ventilation is tolerably voluminous, but a few books, now over a quarter of a century old, give with much uniformity of repetition all that is written on the subject.*

Most writers are diffuse. The theory of ventilation has been based upon considerations rather than investigations. Views have to be supported in lieu of facts ascertained. The experiments and observations in

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* A Course of Experimental Philosophy, by Dr. Desaguilliers, London, 1723; Conducting Air by Forced Ventilation, by the Marquis de Chabannes, London, 1818; Principles of Warming and Ventilation, by Thomas Tredgold, London, 1824; Theory and Practice of Warming and Ventilating, by an Engineer (anon.), London, 1825; Popular Treatise of Warming and Ventilation, by Charles James Richardson, London, 1839-56; Practical Treatise on Warming of Buildings, &c., by Charles Hood, London, 1844; Illustrations of Ventilation, by Dr. David Boswell Reid, London, 1844; Dictionary of Arts, etc., by Dr. Andrew Ure, London, 1846; Practical Treatise on Ventilation, by Dr. Morrell Wyman, Boston, 1846; Traité de la Chaleur, par E. Péclet, Paris, 1843-1860; Etudés sur le Ventilation, par Genl. Arthur Morin, Paris, 1863.

The above is merely a list of the more important works. A complete list for this century is perhaps fifty volumes, mostly since 1850, with possibly important articles in a hundred periodical or serial publications. It is proper that the most valuable recent work should be named, wherein the physiology of ventilation is most clearly set forth, to wit: Military Hygiene, by Dr. Edmund Parkes, London, 1863. The last edition of this work is edited and enlarged by Dr. F. S. B. François de Chaumont, London, 1878.

The indispensable library books of reference in the above, are Wyman, Péclet, Parkes, Reid, Tredgold, Hood. * * *

the direction of chemical or pathological inquiry, have in a great measure failed to give results compatible with evident physical wants. Ventilation of occupied places, in general, means only the supply of air for health and comfort in requisite quantities. But the uncertain element in this simple proposition is, what quantities are requisite ?

The real quantity of air impaired by any one individual is small in any case, although it varies in amount with all the conditions of life and health of the individual, especially also for any one individual as to rest or activity, until limits three times in excess and one half in diminution of what is impaired in the state of comparative rest, are reached.

In air, at mean temperature of 60 to 70 per cent. of hygrometry, an adult man, when awake and at rest at his ease, in similar condition in general to one of an audience in a public hall, may be taken to make 16 respirations, of 30 cubic inches each, or 480 cubic inches, in a minute.* This inhaled air at say 70 degrees will have, when in American summer condition of humidity, about 70 per cent. of complete saturation, or about $1\frac{7}{10}$ per cent. of its volume will be aqueous vapor, and about $\frac{4}{100}$ of a per cent. of its volume will be carbonic acid, while the remainder will be nitrogen and oxygen in the usual constant ratio of about four to one which exists everywhere in the atmosphere. The exhaled air will be found to have lost about one fifth the oxygen inhaled, by the formation of carbonic acid; it will have nearly three times as much aqueous vapor, and nearly 100 times as much, or about 4 per cent. of its volume, of carbonic acid ; while, notwithstanding the greater density of this carbonic acid gas, in consequence of the increase of temperature from 70 degrees to 90 degrees, and also of the levity of the aqueous vapor, the exhaled air is really about 3 per cent. lighter than the inhaled air.

This statement of the figures of respiration has been carefully prepared, and may be implicitly relied upon. It is presented in the outset of this paper, as a foundation on which to build much of the argument to follow, and is especially intended to meet two popular fallacies.

The opinion is entertained by many people, some of whom ought to have informed themselves better, that the expired breath is heavier than the air, and, as a heavier body it falls to the ground. The contrary is certainly the case. Notwithstanding the direction given to the breath when breathing from the nostrils, the column of breath ascends in all

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* Experiments of Dr. Edward Smith. Proc. Roy. Soc., 1859.

places where the temperature of the air is below 85 degrees. The diffusion of the exhaled breath, that is, its mixture into air near by, will of course take place nearer to any person when the flowing off of the stream of exhalation is impeded by the want of difference of temperature between the breath and the air. In any room at the temperature of comfort, 70 degrees to 72 degrees (with proper humidity), the diffusion of the breath will occur above the heads of the persons, and the fresh air for inhalation will be derived from the current ascending along the person ; a current induced in part by the ascensive force of the expired air, and in part by the bodily heat of the person himself. This assertion is to be qualified, however, by admission of effect from established or enforced currents of artificial ventilation, which may modify, or even reverse the natural flow.

The second popular error is that the carbonic acid of itself separates and falls to the ground by virtue of its greater specific gravity (as a pure gas), than that of air. This is altogether a mistake. Carbonic acid has a density as compared with dry air of the same temperature, of 1.524 to 1. It can be poured from one vessel to another as water is poured, but for all that, it "diffuses" or dissipates itself very rapidly, and when once diffused, no length of time effects the least settlement or separation. There will be no less carbonic acid at the top of a tube 100 feet high, than at the bottom. Carbonic acid, if colder than the air above it, will diffuse more slowly ; if warmer than the air near it, so as to be more close to the same specific gravity, it will diffuse more rapidly. Whisky will lay on the top of water without mixing downwards, but once mixed with water, nothing but distillation will separate the two liquors. In point of fact the carbonic acid emitted with the breath, is thoroughly, completely and inseparably mixed with the breath ; and the expired breath itself, as a whole, is rapidly, almost instantaneously absorbed and inseparably mixed with the air of the room.

A man vitiates more air than is needed for respiration ; an uncertain quantity of fresh air is both needed and vitiated in each minute by transpiration. A constant exhalation of carbonic acid transpires from the skin, by no means so large as that emitted from the breath, but probably one-fourth or one-fifth as great. The regularity of this transpiration nearly equals that of respiration. Accompanying this, it is probable that an absorption of oxygen corresponding to the equivalent of oxygen in the carbonic acid takes place. Experiments do not seem to have found the expired air from the the lungs has lost more oxygen than

the carbonic acid exhaled required, whence it follows, that the supply of oxygen to form the carbonic acid transpired, must be absorbed concommittantly. If now it be accepted, that air containing the proportion of carbonic acid existing in expired breath is utterly spent for the purpose of breathing over again, and if an allowance of air for transpiration be made, it is established that each person in still life, requires 580 to 600 cubic inches, or from 0.33 to 0.35 of a cubic foot of fresh air each minute, for perfect ventilation. Even this quantity can be reduced, as it is well known that in diving bells men do live, and do continue to work when the proportion of carbonic acid in the air of the bell rises to 8 per cent. instead of 4 per cent. as it is found in once exhaled air. Carbonic acid is an innocuous gas, quite harmless to animal life, except when it is substituted for oxygen in the air for breathing, and except also, in so far as its presence in large proportions interferes with the natural secretions from the lungs, and possibly from the skin.

Besides the carbonic acid, as one of the vitiations of exhaled air, there is known to exist a large proportion of aqueous vapor in the exhaled breath. Only $1\frac{7}{10}$ per cent. in volume of the air inhaled at 70 degrees, is vapor, while 5 per cent. of the same volume is exhaled at 20 degrees higher temperature. (By weight the quantity of vapor will have been increased as 35 to 100.) To this excess of exhaled vapor derived from the lungs or fauces, there is to be added a large, but very variable quantity of moisture imparted to the air of a room by insensible perspiration from the skin. The natural internal warmth of the body is very nearly 100 degrees Fahr., regardless of the heat of the external air, and comfort and health, even existence as a living animal, depends upon the abstraction of heat from the surface of the body, so that the heat generated in the vital functions shall not elevate that internal temperature sensibly for any considerable length of time.

This part of my argument was more fully discussed in the paper "on the relation of moisture in air to health and comfort," which was read by me before the American Institute of Architects at their meeting at Boston, in 1877. It was therein stated: "There are three means provided "for the healthful dispersion of animal heat. The first is radiation to "surrounding colder objects; the second, conduction to the atmosphere, "which, for comfort, must be sensibly cooler than the body; and the "third is, evaporation from the moist surfaces of the lungs and throat,

" and evaporation from the roots of the pores of the skin. The first of " these means—to the clothed person, at least, is comparatively ineffec- " tive, while the relative quantities of heat which may be eliminated in " any given time or locality, by the last two, will probably be found " nearly equal, in an atmosphere of about 70 degrees temperature and " of 65 to 70 per cent. humidity."

It may be assumed, as the conclusion from data established by many experiments and observations, that $1\frac{5}{10}$ to $2\frac{5}{10}$ pounds of water are evaporated each day from a person in still life, or from one not taking violent exercise, nor exposed to heat varying essentially from 70 degrees Fahr. This quantity of two pounds, gives, under the conditions previously accepted, about three and a half times as much vapor evaporated by insensible perspiration, as would be evaporated by breathing. If it be supposed that the moisture from insensible perspiration is to be absorbed and taken up by air of 70 degrees and of 70 per cent. humidity, so that this air shall become saturated with humidity, it then follows that no less than 4 cubic feet of air must be supplied for this purpose to each person each minute.

Aqueous vapor (which is merely the accepted name for steam in its invisible condition below the boiling point of water) is, like carbonic acid, an innocuous gas, quite harmless to animal life, except in so far as its presence in large proportions interferes with the natural secretions.

It would almost seem, from these statements as to the harmless character of respired gases, that the word vitiated was misapplied to exhaled air.

There is present in air, in general, a certain amount of gaseous impurities. Ammonia, sulphuretted hydrogen, and sulphurous acid gas, with numerous others of local derivation (especially near towns or cities), are found in very small quantities. So small that the hundredth of a per cent. is to be taken as a unit in measuring them. But besides these gaseous impurities, there always exists in air of inhabited regions very small quantities of floating organic matter, composed of fragments of organic origin, vapors of the same source, like odors, for instance, microscopic germs or living organisms, together with dust of minerals or metals, smoke, etc., forming an insignificant part of the atmosphere, nearly inappreciable by weight or measure, but of the greatest importance in effect upon the air of ventilation.

The dangerous vitiations of air by respiration or by perspiration, are

those which proceed from the decomposible organic matter exhaled or emitted. This organic matter appears to be carried to large extent by the aqueous vapor, although much of it exists as floating dust; and small particles of skin, fatty substances, bits of hair can be caught and identified by the microscope. The quantity of such organic matter is exceedingly diminutive as compared with any given volume or weight of air. Doctor Angus Smith (the only authority, but his authority is sufficient) concludes that not the one hundred-millionth part of its volume for pure air on high ground, or about the one five-millionth part in a crowded railway carriage, is organic impurities. Yet to a very small portion of this very small portion of air is attributed the danger from breathing vitiated air. In all probability the origin of disease can be found only in atmospheric germs of living organisms, which find the perpetuation of their vitality in the decomposible and decomposing organic matter suspended in the atmosphere, and which are disseminated through the agency of the same atmosphere.

The quantity of carbonic acid exhaled in a given time by any number of persons is nearly uniform, and also the proportion in free air is quite uniform, so that the proportion of carbonic acid present in any occupied room can be taken to represent very accurately the degree of vitiation from respiration. Not that the carbonic acid itself is dangerous or unhealthy; but by its presence in excess of the normal quantity, the organic matter proceeding from persons occupying the room, and the related unhealthiness can be estimated. The measure, however, is not a positive one, as a relationship to the degree of moisture in the air of any room is one of the conditions of the decomposition of organic matter, so that vitiated air laden with moisture may be considered more dangerous than the same air comparatively dry, and this regardless of the carbonic acid present.

This very long preamble to the real subject of this paper has been made because the writer felt it necessary to substantiate fully his fundamental propositions as to the absolute and demonstrable quantities of air needed for ventilation.

So far as carbonic acid and vitiations proceeding from the breath are concerned it is evident that only a little over one-third of a cubic foot of pure air is needed each minute, provided the entire volume of vitiated air be removed without mixture in the same time. So far as moisture or aqueous vapor emitted is concerned, about four and a half cubic feet per

minute supplied at 70 degrees and of 70 per cent. of humidity, will suffice to prevent the deposition, if the air be evacuated at 70 degrees and in the condition of saturation. While if it be admitted that the effluent vitiated air of the room has a temperature of 72½ degrees, its condition of humidity when carrying the same amount of vapor will be only 90 per cent. Whence four and a half cubic feet of air per minute (under these conditions of supply) is enough to remove all vitiated air from personal sources, to furnish perfectly fresh, pure air for respiration and to provide an *atmosphere* four or five inches thick around a standing individual, which *atmosphere* will ascend around him, and be supplied from beneath, at the rate of motion of about three or four feet per minute.

This proposition for the absolute ventilation of an individual has been stated in all its baldness to make its impracticable character emphatically evident. Men are not going to be ventilated in cases, even to secure perfectly fresh and healthful air. The purity of air in any occupied place can only be relative. The sole mode of removal of vitiated air possible is by diffusion and dilution. A much larger quantity of air will have been supplied or permitted to enter into a room, and will be removed or allowed to escape than is needed for the use of the persons occupying the room, during the time of their occupancy of the same; and the room itself will have a definite cubical capacity, and form an intermixing chamber for the fresh and vitiated air.

We have now passed all exact computation and come into a field of guesses and assumptions. With a definite supply of air to any room (which supposes in some way a corresponding efflux) a certain quantity of exhalations and emissions will eventually approximate to a definite ratio of the constituent parts of the air within the room. If it be supposed that twice the quantity of carbonic acid is admissible in a continuously occupied room, over that existing out of doors in fresh air, then ninety-five times as much air as is needed for respiration, etc., must be supplied to dilute the exhaled air. A proportion which gives about 32 cubic feet of air per person per minute, with a result of 0.0008 volume of carbonic acid present. If it be supposed that the hygrometric condition of the air is limited to an *increase* of 5 per cent. of the humidity in air of 70 degrees, then the absorption of vapor demands 25 cubic feet of air to each person per minute. These neat results from computation would be very satisfactory, if there were any grounds for the assumption of 8 parts in 10000 as the exact ratios for carbonic acid and air in rooms,

or for acceptance of 5 per cent. of humidity in place of some other ratio, smaller or larger.

The whole matter, then, resolves itself into opinions as to individual personal comfort, and to observations upon healthfulness of some of the very few rooms and places where, for a period of time, more or less extended, a definite ventilation has been maintained.

It seems pretty well established, for rooms continuously occupied by persons, either in good health, or at least not subject to offensive disease, that 30 cubic feet of air per person per minute, if of proper temperature and humidity (temperature and humidity being considered to have related values), (and if adequately introduced and removed into and from rooms, which have a cubic capacity of not less than 1 000 cubic feet per person), will pleasantly, healthfully, and satisfactorily ventilate such rooms.

When one considers the various conditions comprised in this rule, he will comprehend how generally inapplicable the fixed rule of thirty cubic feet per person per minute becomes. The condition of the persons as to health, etc., will change the figures from thirty to sixty for surgical or obstetrical wards in hospitals. While for some diseases even the larger quantity will not remove offense, and for yet others no quantity of air can be named sufficiently large. Increase of temperature and humidity, for degrees and percentages above 70 degrees and 70 per cent. of humidity, begin to demand larger quantities of air for comparative comfort; with 90 degrees out-of-doors, and 60 per cent. to 70 per cent. of humidity, even 60 feet per minute is not an excessive quantity of air, where 30 is named above.

The continuity of occupancy and cubic capacity are in some respects interchangeably related values. Where any room is to be occupied for a short time only, its cubic contents may be taken as so much fresh air, and deducted from the amount of air required for ventilating the same room for the same time. Thus let it be supposed the room itself has the cubic contents of 1 800 feet; that one person alone occupies this room for an hour (supposing it to have been filled with fresh air at the commencement of the time), and that no fresh air is supplied during the hour; the degree of vitiation will only have reached the point which would, eventually, have been attained in a continuously occupied room, where 30 cubic feet of air had been regularly supplied each inmate. This almost self-evident proposition is of the highest importance in ven-

tilation. The homes of those in humble circumstances, and even of those who live in moderate ease, are made healthful, not by abundant constant supply of fresh air, but by frequent freshenings of the air of dwelling or sleeping rooms. No systematic ventilation, however well devised and constructed, however extensive its supply of fresh air, however regularly or judiciously operated, can afford to dispense with repeated displacement of the air of rooms, and substitution of entirely fresh air through open windows and doors, at times during all seasons of the year. This law of change of air taken in connection with a limited supply during time of occupancy, applies directly and at once to the halls of audience, the ventilation of which is the theme of this paper

In all civilized countries, people congregate in churches, halls, or theatres for devotion, instruction or amusement. The ends of government require legislative and council chambers and court rooms which have at times crowded sessions. There are thousands of rooms in this land, and in other countries, in which crowds are gathered and often packed for sessions of one to six hours on the average, with occasional sessions, in some legislative halls in particular, of twelve and sometimes more that twenty-four hours. Anything may be called tolerable that is tolerated, anything may be esteemed endurable that is endured. Churches, halls, schools, theatres, State houses, court rooms, etc., are rendered tolerable when judicious care is taken in changing the air after a session, and in having fresh air in the audience rooms, at the commencement of the same. They are endurable —not only can little illness or actual disease be traced to them as places of origin, but on the whole, the audiences, accustomed or habituated to the closeness of the air which accompanies any lengthened session, cease to notice what would be excessively disagreeable to a new-comer into the confined room. People do not willingly find fault where there is apparently no remedy.

Perhaps the most striking example of this salutary effect of occasional change of air as a substitute for ventilation by constant supply, is to be found in our American railroad cars, where, in cold weather, the least of regular supply is furnished to largest number of persons temporarily crowded into the smallest space. To the outsider the heat becomes intolerable ; to the insider it is more tolerable than any draft of fresh, cold air.

To the chemist, the air is found "vitiated" to the extreme, both with carbonic acid and with vapor of water, while it is laden with organic im-

purities that are hastening towards the condition of offensive decomposition. The unhealthful condition of the air, in thousands of cars on any day during six months of any year, cannot be questioned. And yet no serious illness that can be attributed to the want of ventilation, is found amongst the tens of thousands of passengers, and it is well known that the conductors, brakemen, and others connected with the trains, who live in and out of the cars from day to day, are healthy beyond the healthiness of most other men.

Comfort is found in warmth. Whatever supply of fresh air be given, not the slightest sensation of cold must be appreciated from the current of fresh air by any occupant of a room. There is only one exception to this dictum, and that is when a person having come to a sense of oppression from the air of a room (a sense which is almost invariably one of heat and not of badness), voluntarily endures the admission of fresh, cold air upon himself. Such a person will be more likely to enjoy a blast from an open window when the external air has the temperature of zero, than to endure a gentle current of four or five feet per second, of air at 60 degrees to 65 degrees, and 45 to 50 per cent. of humidity. The requirements of ventilation are not positive. Those of comfortable warmth are immutable facts. The air of any room may have become much vitiated, and even offensive, and if its temperature be kept down to the point of comfort, most persons will deem such air to be fresh within the desirable degree of purity, while an overheated room is apt to be pronounced to be "filled with bad air," although the air may be as pure as is attainable.

The popular appreciation of ventilation is founded upon effluvia and heat. Effluvia may proceed from two sources : first, from the decomposition of organic matter exhaled or emitted—a very short time is needed for this decomposition to become apparent—and second, from odors which emanate from the person or clothing of those occupying a room, whether the odor be offensive or defensive. In either case effluvia, when marked as pervading a room, or any portion of it, is a legitimate evidence of inadequate ventilation. The effect of odors, however, on the senses is very imperfectly marked. A habitude is established, and nine persons out of ten of an audience do not realize the degree of vitiation which has been reached by gradual steps during a session, and at the end of the same, when passing to the outer air, the change of temperature will not allow the change of quality to be perceived. Unless one has had occasion to enter the hall during the sitting he will never know the

air had become impure. Heat becomes, therefore, almost the sole standard by which ventilation of halls is judged. The overheated condition, especially of the upper portions of halls, obtains the designation of closeness, and is generally submitted to the limit of endurance, at which point some window near by is opened, greatly to the discomfort, in cold weather, of those on the floor of the hall, and little to the relief of the overheated portion of the room.

Except in very cold weather, crowded halls do not require the supply of much heat. Many halls, with corridors and passages on one, two or all sides, especially auditoriums of theatres, require no more than to be warmed to a comfortable temperature before the audience collects, after which the heat from the persons composing the audience will more than supply what heat is lost at the windows or walls. For ventilating a hall in such case it becomes necessary to introduce air of lower temperature than that of the room. The problem, then, is how to introduce and distribute cold currents of air amongst a crowded audience without producing the sensation of cold to any one of them.

The air supply demanded may not be strictly cold. Its desirable temperature may rise considerably above the proper temperature of the room, and yet it will, in currents, be perceptibly and sensibly cold.

The feeling of cold from currents of air proceeds from two sources: First, the abstraction of heat in warming the air itself, and second, from the absorption of vapor by the air, which vapor will have been formed at great expenditure of heat from the natural moisture of the skin. "The quantity of heat taken up in the vaporization of the moisture of the skin by dry and cold air, compared with that abstracted in warming the air, is so great, that the heat imparted to the temperature of the air becomes much the least in the ratio. Thus air at 35 degrees and of 70 per cent. humidity, demands nearly the same quantity of heat, to warm it to 70 degrees that is requisite to vaporize the moisture which will raise the humidity to 75 per cent. at 70 degrees.* It is very nearly correct to assert that the cool sensation from a breeze in summer proceeds entirely from the evaporation of moisture thereby induced. A current of saturated air at 100 degrees will neither remove heat by contact nor by induced evaporation, and is consequently incapable of producing a cooling effect; while as the temperature or the degree of humidity is sup-

* Vide addenda to paper "On the Relation of Moisture in Air to Health and Comfort."

posed to fall, the same velocity of current becomes first a pleasant, cooling one, and next a decidedly cold one. With a high temperature and dry air the cooling effect of a current (even at 100 degrees) may be pleasant to the sensation, but will be attended by sun-burning (even without exposure to the sun), and blisters will be produced by the excessive deprivation of moisture, from the cuticle or surface of the skin. With 80 degrees of heat and a high dew point a strong breeze is not unpleasant, nor likely to be injurious, after the person shall have acquired some accustomed habit of body to endure it; but at 70 degrees and a low dew point, which is the only possible condition of heated air in mid-winter, the annoyance of a current of even five feet per second and its unhealthiness are positive facts." *

It is proper that I should advert at this point in my discussion, to the marked differences of the variations and requirements of warming and ventilating that exist in this country from those which are found in England or France. The subject has been considered in the paper "On the Relation of Moisture in Air to Health and Comfort," but it may be now again referred to, in support of the view that American practice should be directed to meet the special requirements of American conditions, and not to conform with other requirements, however well established in themselves. As was set out in the paper "On Moisture in Air," it seems at first inexplicable to an American how the statement can be made by foreign writers that 56 degrees to 62 degrees Fahrenheit are comfortable temperatures for living rooms, when in cold weather he is scarcely warm at 70 degrees, and in mid-winter is not overheated at 80 degrees, although clad at the time in the thickest of underclothing. The fact is that the deprivation of heat from the person is greater from the evaporation of moisture than from radiation or convection of the air, and the hygrometric state of the atmosphere has so much influence, as to make a temperature of 56 degrees in Ireland, the West and South of England, or in Normandy, sensibly as warm as 80 degrees in Canada or Minnesota at about the same season of the year.

All mankind complain of the weather, and an Englishman especially. But there are in England, eight months of the year, when the thermometer ranges between 40 and 60 degrees in the shade (and there is very little sunshine), with a dew point so high that it is a pleasure to

* Quoted from a paper by the author, on the Ventilation of the Hall of Representatives, Washington, 1876.

exercise in the invigorating air; one month of 60 to 80 degrees, and three months from 25 to 50 degrees. While in Northern America there is scarcely one month (or 30 days) with the average temperature of 50 to 70 degrees (temperatures which, from the difference in humidity, correspond sensibly to 40 to 60 degrees in England), and there are about three months from 75 degrees to 90 degrees, three months of 30 degrees to 50 degrees, and five months of excessive variation of temperatures from zero to 40 degrees or 50 degrees, these last five months having about 30 days of warm weather at intervals. During the three hot months, and also during the five cold ones, open air exercise to those whose avocations are generally within doors, is almost impossible. Any one, who is called upon to endure the fervid summer heat, or who will habituate himself to the inclemencies of our Arctic winter, will not suffer great discomfort therefrom; but the weak and the tender, the workman of the factories, the tradesman of the shops, the merchant in the counting house, the student at the desk, cannot acquire the endurance or the habit, and must shelter or warm themselves.

It follows that the ventilation of halls in England for eight months of the year is simply the quiet introduction of a given quantity of external air, little or no increment of heat being necessary, and for three-twelfths of the year the similar introduction of air, heated 15 degrees to 20 degrees. There is one month of altogether open windows; but except on a few very stormy days, there are few times when relief from overheat or closeness in a room, cannot be obtained without serious discomfort, by partial or controlled admission of external air, directly from windows. The small addition of heat demanded at any season, and especially for the most of the year, prevents the adoption of our system of ventilation by means of warmed currents of air. The use of the levity of the entering current ceases to be available, when that current must necessarily be only very little, if at all, higher in temperature than the room itself. On the other hand, the operation of an exhaust system, where an exhaust shaft or fan is made to remove air from the room, becomes eminently feasible, when the general conditions are such that the outer air may be taken in freely, at any provided or arranged inlet, without discomfort from its want of heat. The great support of the exhaust system for American usage is derived from English authority and example, together with its applicability to ventilation for the American single month of the year, of 50 degrees to 70 degrees, when closed

windows and a supply of unheated air is the requisite for occupied places.

Our season of open windows is longer than that of England, but it is also much hotter, and we are constrained to some forced supply of air during the hot season to render audience halls tolerable. Our term of mean temperature is so brief that its especial consideration may be neglected for audience halls; but for asylums or hospitals this term must be adequately provided for. The real point of discussion is how to warm with an average temperature outside of 25 to 30 degrees to the inside temperature of 70 degrees to 75 degrees, and how to supply with the warming, sufficient air for breathing and for the preservation of relative purity.

There are two respects in which ventilation of halls becomes easier in America than in England. The greater humidity of the English climate prevents the dispersion of exhaled vapor with the same rapidity as with us, and exhaled vapor is laden with organic impurity on the verge of decomposition. Only a very few minutes are required for surcharged air at the temperatures usually existing in close rooms to become offensive. The fœtor of a long occupied hall in England is distinctive to an American and unapproachable in a dryer climate. In another regard we have, in the court rooms, theatres and public buildings in general in America, the advantage of superior cleanliness in dress and person for a considerable portion of the audiences. We have comparatively no ower order to ventilate against.

Returning from the long digression of comparison of American with foreign requirements, to the consideration of absolute requirements and practical demands. The following has been established by the previous argument, that for the support of life, each person must have one-third to one-half a cubic foot of fresh air each minute. That for the conservation of temperature to the point of comfort, each person supplied with air at 70 degrees in its usual condition of summer air in America, must have four to four and a half cubic feet per minute. That to maintain the freshness of air in a continuously occupied room, so that it shall be pure to the sense of smell—a condition which is found to correspond generally to the presence of 8 parts of carbonic acid to each 10 000 parts of air, about thirty cubic feet of air, per person per minute, is requisite. It has been shown also how audience halls, without systematic ventilation, or at best supplied with very limited quantities of air, are, if of

adequate cubic content in comparison to the number of persons present, and if occupied only in short sessions, and if judiciously supplied with fresh air between the sessions, relatively healthy, comfortable and acceptable to the persons attending them. The point for enquiry which now follows is, what is the practical limit for quantity of air to be *systematically supplied ?*

The proposition before established, that the cubic contents of the hall can be reckoned as part of the supply itself, by taking the number of minutes the hall is occupied by a certain number of persons, becomes now of importance in fixing the limit for momentary supply, when the average length of session can be assumed. But this is really of less importance than would appear from mere statement. On the whole, in audience halls, the cubic capacity per sitter, will be found to be from 200 to 300 cubic feet, or only 6 to 10 minutes supply of air to each person, where the final relative purity is to correspond to a supposed regular supply of 30 cubic feet per minute. If this cubic capacity is to be taken in addition to any regular supply for a given length of time, then if 100 minutes (1 hour, 40 minutes) are taken as the length of the session, two to three cubic feet of air per minute becomes available as an addition to whatever is supplied.

The practical difficulties in ventilation of halls which effect the quantity of air to be supplied, are those of introduction and of distribution. The difficulty of introduction is perhaps the most serious trouble. Dr. Reid's proposition for a perforated flooring, would seem to present a satisfactory solution, and it is questionable if justice has been done the reputation of the scheme by the public, for the method continues in operation to this day, with twenty-four years' service at the Houses of Parliament; although embarrassed in its action by singularly unmechanical and inefficient apparatus for warming and supplying the air. It cannot be claimed, however, that the construction of a sub-hall for equalization of pressure, will meet the approval of architects or builders in future, and Dr. Reid's effort will probably remain as an example, rather than be accepted as a model. But Dr. Reid was for a whole life time of arduous labor, an intelligent and careful observer of the requirements for the ventilation of audience halls. As the result of his study he concluded, and he expressly states his conclusion as with diffidence, that 10 cubic feet of air to each individual would suffice to properly ventilate a hall. His great effort

was to arrange to supply this quantity in such way as should be at once effective and imperceptible to an audience. Much of his want of success laid in the imperfections of his mechanisms, in the coils or heating surfaces, and in the fans or means of impelling air. Some of it laid in the effort to regulate the audience as well as the ventilation. His life-long difficulty was found in the establishment of local currents engendered by his imperfect apparatus, and from the sensation of cold which such currents produce.

Systematic supply involves arrangements of ducts and passages by which the outer air, from some chosen point, shall be transported to certain desirable mouths of delivery or inlet registers. The dimensions to be given these ducts or passages are absolute and positive ones, when the quantity of air to be moved shall have been established by the number of persons and their supply, and when the velocity of movement of air is determined or accepted. The velocity of movement is limited on the one hand by the motive power applied to impel or effect it, that is, by the expenditure of force demanded; which means in the end, whether impulse by fans and engines, or a draft from a heated flue be used, expenditure of fuel; and on the other hand by practical dimensions accepted in construction of the ducts or passages.

In figures, ducts for forced ventilation must suppose currents of from 600 to 1 200 feet per minute, with some allowance of sectional area for branch ducts, which shall admit a less velocity of flow through them; while ducts for currents induced by exhaust shafts, or produced by the entry of heated air, at the usual temperature of steam heated currents, will have a usual velocity of from 150 to 300 feet per minute—sometimes, under favorable conditions for making a draft, rising to 300 or even to 600 feet per minute.

Systematic supply involves also the heating of air to be supplied, in an extreme case, from 5 degrees to 10 degrees below zero up to perhaps 75 degrees, in such extreme case of cold weather. Ventilation is not attained except at cost for fuel, and a reasonable expenditure in this regard will meet approval when restricting the amount of ventilation to the necessities for health. The heat *will* in all cases be that of comfort or the *system* will be discarded.

Finally, the writer has sought with diligence and study to determine from irrefragable data, the exact quantity of fresh air that should be supplied to each person of an audience per minute, and he now finds

himself compelled to admit that no such data exists. That the quantity must be taken to have an arbitrary value founded on economic and structural, as well as upon medical and chemical considerations; that this value must have its authority from its general acceptation by the community or by its general acceptance by investigators, who will have considered the question from all points,

It would seem that for audience halls occupied for sessions not exceeding two or three hours duration, Dr. Reid's value of ten cubic feet of air per minute, is all that should be arranged for when planning such halls—all that can be judiciously urged in the accomplishment of ventilation in view of the cost in fuel and apparatus, quite sufficient to meet the physiological issue, and so large, that it ought to be accepted from the medical point of view. This quantity might be referred to the maximum seating or holding capacity of the room to which it should be applied, when its partial occupancy would go towards increasing the general supply. And it should be referred to the coldest weather heating power of the accompanying heating apparatus, so that in case of emergency of lengthened sessions in milder weather, and in hot weather, the quantity could be materially exceeded. When a forced ventilation by means of a fan is adopted, the flues and passages should refer to a winter ventilation at half speed of the summer one, and the quantity of summer ventilation would then become twenty cubic feet per person per minute. An amount of ventilation which, with open doors and windows, would, if the ventilating currents are suitably distributed amongst the audience, prove ample to give all the comfort possible to a crowd gathered in hot weather.

For audience halls in legislative buildings, there is a propriety in adhering to the larger quantity of air, which has been mentioned as needful to preserve the sensation of pure air to the smell in continuously occupied rooms, to wit, thirty cubic feet of air per person per minute. As before, this quantity should be referred to the maximum attendance in any hall, and the capacity of the heating apparatus be referred to the coldest weather for such quantity, so that the forced ventilation should be adequate to give a double supply in mid-summer.

In the mind of the writer there can be no question whatever as to the direction of ventilation in a hall. A man lives in an ascending current of air—he is enclosed in one. In a crowd, without ventilation, a circulation takes place; in some way the roll of air which rises above

one's head is replaced by cooler air sucked in sidewise at the feet, or downwards, between the persons who form the crowd. If fresh air can be, and is, introduced imperceptibly at the floor near the person who needs it, the rising current supplies, nearly unmixed by diffusion, the air for respiration, while the vitiated air is swept upwards with the advantage of its levity as well as of the current of supply. A downward system of ventilation, on the other hand, where the air is supposed to be abstracted at the floor, near to the individual, supposes a thorough admixture, mechanically, of the respired and vitiated air with the descending sheet of fresh air. Within any hall where the air enters at the top, there could scarcely exist any fresh air whatever, while the degree of vitiation would increase downwards, until the occupants of the hall would breath and live in the vilest air possible for any given supply of fresh air.

There is also another matter to be thought of in ventilation of halls—the ventilation of the gas lights, and besides this ventilation, the removal of the heat they generate. The ordinary gas burner consumes 4½ cubic feet of gas per hour. Each burner may be taken to demand 2 700 cubic feet of air per hour or 45 cubic feet of air per minute, when the temperature of the gases of combustion, including the 45 cubic feet of air, becomes, for open burners, as high as 99 degrees, and for Argand burners possibly as high as 128 degrees. In an upward ventilation the gas lights present little difficulty, as the air for ventilation of the persons composing an audience will commonly exceed in quantity the greatest requirements for gas burning. The vitiations arising from gas lights are very objectionable when the attempt to introduce air strictly at the ceiling is made. The figures given here as to the requirements of gas lights will allow provision to be made for them in arranging the ventilation of halls. The radiation of heat from gas lights of a brilliantly lighted room becomes not only an important addition to the heat of the air, but also to the heat of the occupants of the room, independent of its temperature in some degree. This effect of gas light is sufficient to reduce the desirable average temperature of a gas-lighted room, some two degrees to five degrees, and the necessary temperature of admitted air should fall off in like degree. No amount of ventilation will make it comfortable to sit near the great chandelier.

It is a source of great gratification to know that the electric light has reached that point of development where it has become available for

lighting audience halls. The practicability of electric lighting at present is found in the production of large quantities of light. As the introduction of gas light led to the use of much greater illuminating power than was obtainable by candle lighting, however numerous and sparkling the candle lights may have been displayed from reflecting sconces or chandeliers hung with lustres in old times, so the electric light also overpowers the gas light wherever substituted, to much the same extent. The electric light is the nearest possible to the natural one of the sun. Properly arranged, to avoid distinct shadows, the correspondence to a carefully shaded room with ample mid-day light can be secured. Lighted from above, a complete avoidance of objectionable glare can be effected. Colors will have natural tints and values, and the gratification of our most delicate sense, is not the least of promise in the perfection of electric lighting.

The vitiation of air by the electric light, arising from the slow combustion of the carbon, is too insignificant to form any element in considering the ventilation. For an equal quantity of light, there is generated seven hundred times as much carbonic acid in coal gas lighting as in electric lighting. There is a small amount of vitiation from the electric light in the form of nitric or nitrous vapors, which may or may not accompany coal gas burning to equal extent where equality of light giving effect is made the standard of comparison. But this quantity of vitiation is also utterly harmless, in the volume of air demanded for ventilation of the number of persons who are to derive their light from any given electric source. The heat effect of electric lighting is as favorable to the ventilation and comfort of audience halls as any other advantage presented. Thus, the same light-producing capacity gives thirty-four times as much heat for gas lighting as for electric lighting with equivalent light values, as the most unfavorable showing of the electric system, supposing all the force expended in the electric arc is transformed into heat. Furthermore, the superior safety of the electric light as regards danger from fire, is not the least of its recommendations when enumerating advantages. At the present time the cost of electric lighting, with liberal allowance for use and deterioration of apparatus, is about one-half that of gas lighting, when the same quantity of light is supplied; but in view of the superior lighting usually practised when the electric system is introduced, the two methods approximate to the same cost generally.

Resuming the discussion of ventilation again. It must not be accepted from the foregoing remarks on downward ventilation that the removal of air at the floor of a hall is wholly impracticable. In rooms of limited floor area, like school rooms, an arrangement for supply and removal of air in conformity with the great natural circulation which occurs in all heated rooms, is likely to prove successful in those conditions of the weather which demand warm rooms. And as has been shown in our climate, there is but about one month in any year in which closed windows are desirable, *without an attendant supply of heat to the room*, it follows that such school rooms may be effectively ventilated during the eight months when our temperatures vary from zero to 40 degrees or 50 degrees, that is for seven-eighths of the time when windows are closed. By judicious manipulation of windows and of eduction flues and their registers, the ventilation during the one month of closed windows without fire may be ameliorated, if not made altogether efficient.

Again, in churches and lecture rooms, where the economy of apparatus and of operating is esteemed superior to ample but expensive ventilation, the systematic provision and removal of much smaller quantities of air, than have here been shown needful for desirable purity may accomplish much improvement in the direction of relative purity. The habitual method of warming a church building in America is by means of several hot air furnaces, placed in the cellars underneath, as sources of heat. These furnaces having usurped the functions of the close stoves, with long lines of smoke pipes, which were formerly a peculiar feature of the "meeting houses" of our fathers. The furnaces have just about the same heating capacity, and the distribution and circulation of the heating currents within the walls of the church is effected in much the same way. When actively employed in warming the church by means of furnaces, there is a supply of fresh heated air, considerable, perhaps, in itself, but inconsiderable, at its largest quantity, to the wants of ventilation of the numbers present. The control of temperature of the heating currents is very limited, the lowest temperature being commonly about 180 degrees, while the highest, often demanded in the coldest weather, rises to quite 300 degrees, and sometimes above this point; and the control of warmth in the church itself is obtained by closing or opening—registering off—the hot air current. In ordinary cases, the registers are shut soon after the commencement of any session, and if

the room be well filled, the heat of the persons present (especially at evening meetings where gas lights increase this heat) causes it to become overheated long before the end of the hour, or hour and a half, of usual session.

The equilibrium of temperature in such a room, is established solely by the cooling effects of the walls or windows, downwards along which there falls a sheet of cooled air (augmented in cold at the windows by leakages inwards at the bottom of the same), a sheet which flows inwards towards the register openings, and is directed upwards with the flow from them ; or when the register is closed off, the sheet forms part of the current of personal origin rising in the middle of the room. This roll of circulation goes on continually, and at some degree of elevation of temperature at the top of the room, the lower strata reaching to the height of above a gallery sometimes, will be found to have attained some uniformity of heat. In fact, when filled with heat, as the furnace constructors denominate it, there will, in a church building of 35 to 45 feet in height, be less than 10 degrees difference between the floor level temperature of air and that taken 20 to 25 feet above such level. No large ventilating shaft can be taken from the upper part of such a room. Even the small opening to remove the gases of combustion of a chandelier disturbs the circulation of heat and intensifies the cold descending currents near the window, besides accelerating the leaks of cold air at the cracks; so that the ventilation of churches thus heated, is practically limited to what leaks *out* of heated air, at or near the top of windows, and what leaks *in* of cold air, at or near the bottom of the same. A systematic leakage, which on windy days is modified by all leaks *in* at the windward windows, and all leaks *out* at the leeward ones. Now a kind of semi-ventilation of a church thus warmed and arranged can be effected by removal of air, at or near the floor, by means of ducts connected to an exhaust shaft ; all of which will become operative if the currents from the hot air registers have been augmented to meet the requirement of air, by tempering the heated currents with direct currents of cold air, to desirable heat and quantity. Here it is seen that a downward ventilation, under conditions, may effect a good purpose to a certain extent.

It will not be attempted at this time to argue fully the advantages of the method of supplying air for ventilation by impulse through mechanical means—the superiority of forced ventilation, as it is called. This mooted question will be found to have been discussed, argued and

combated on all sides, in numerous publications, but the conclusion of all is, that if air is wanted, in any particular place at any particular time, it must be put there, not allowed to go. Other methods will give results at certain times or seasons, or under certain conditions. One method will work perfectly, with certain differences of internal and external temperatures, while another method succeeds only when other differences exist. One method reaches to relative success whenever a wind can render a cowl efficient. Another method remains perfect as a system, if no malicious person opens a door or a window. No other method than that of impelling air by direct means, with a fan, is equally independent of accidental natural conditions, equally efficient for a desired result, or equally controlable to suit the demands of those who are ventilated ; which last requirement, it will be shown further on, is more essential than to meet their necessities.

To many people it is a favorite belief that ventilation should be in some way effected by a natural process. Windows and doors and open fires are the limit of artifice to be endured, houses being *presumed* in lieu of caves. There may be a fireplace with its chimney in the category of *natural* apparatus, although this was as artificial and as abstrusely ingenious to our ancestors of five or six hundred years since, as the best steam or hot-water heating apparatus is to us to-day. Perhaps to quote from my former paper on moisture in air will be the best answer to such persons: "Clothing, houses and fires are the means by which mankind is enabled to inhabit the earth. It is an artificial existence for an animal whose natural life would otherwise be limited to a small belt of the torrid zone, where the temperature never falls below 80 degrees, nor rises above 100 degrees." Fresh air will not be supplied naturally to a person in an audience hall, as one obtains it on a mountain top, at the sea-shore or upon the deck of a vessel. Neither the currents nor the temperatures of the healthful breezes are admissible in the processes of *ventilation*, so that the natural supplies cannot even be simulated artificially. To meet the demand for health and comfort in the natural gregation of men, which is one of the conditions of advancement in civilization, ventilation and warming must be effected with unnoticable means and yet with positive results. Success in ventilation of halls can only follow the complete adaptation of mechanical appliances and apparatus, as well as of structural arrangements, to the ascertained wants and requirements of the individuals composing an audience. In all mechanical appliances that is sim-

plest, which most positively and directly effects the purpose in view; and in this matter of supplying air it may be claimed that the process of impelling it, when and where wanted, is at once the most certain and efficient, and that the fan (in its form of a rotating wheel with vanes for large uses) is the simplest and readiest machine for impelling air.

It will not be attempted at this time to discuss the theory of Rotary Fans. The fan itself will simply be accepted as one of the recognized appliances in the construction of ventilating apparatuses, available with other mechanisms in established forms and defined types for American practice.

The fans most generally in use for the ventilation of large buildings in this country have been derived, in all essential particulars of conformation, from those designed by the writer for the United States Capitol at Washington in 1855 and 1856. These particular fans were based upon a type given by M. Combes (in his "Aerage des Mines"), where the fan blades or vanes were placed upon the face of a disc; and the fan itself thus constructed, was located in front of a circular opening in the wall of a building, the wall forming one side of the zone of blades, in opposition to the outer edge or face of the disc, which formed the other side. In this construction, no case whatever is demanded for the fan, which receives its air through the central circular opening in the wall, and delivers its air at all points of the periphery into a large but close room; from which room the ducts for conveying air, branch in any desired direction.

The heating and ventilating at the United States Capitol was under the charge of Maj. Genl. M. C. Meigs (then Lieut. U. S. Engineers), who selected this type of fan as presenting certain structural advantages for its employment. The study of the conditions of fan construction which was devolved upon the writer, led to some modifications in the forms of blades, etc., as accepted by M. Combes, with which changes these fans were employed in the ventilation of the United States Capitol buildings. More recently the disc type has been departed from, but in other respects the proportions of the Capitol fans have been followed and have now become established in general practice. It was a recognized necessity that a fan should be reduced to its least practicable dimensions, and the most cursory observation showed that the passage of air through the fan itself was an accelerating flow, whose least velocity should be, that at which the entering air ap-

proached the inner edges of the blades, and its greatest velocity should be, that at which the escaping air left the tips of the blades. The action of the blades being to give an accelerating velocity, to be mainly derived from the increase of velocity of the blade surface as it became further from the centre. It followed as a resulting consequence, that the area of any cross section of the passage through the fan (any one of which will be formed between the disc and wall or case side, and between any two blades), should reduce in proportion as the air accelerates, and that the air should thus be kept in contact with, and be acted upon by the blades as the source of impulse. These propositions gave, for instance, where the disc of the fan was taken to have a diameter equal to one, the diameter of the mouth or central opening becomes seventy-four hundredths; the width of the fan at the mouth becomes seventeen and a half hundredths; while the width at the periphery becomes one-tenth. The number of blades was found (by experiments as to most efficiency with several different numbers), to be about sixteen; a number giving the section of the several passages formed by blades, disc and wall, most nearly a square one, or most nearly that section of a duct or passage, where the sides offer the least resistance to flow of a fluid.

The advantages in effectiveness or economy in power over other fans as before made, with small central opening and great width of vanes in direction of the axis, is not very considerable; 10 to 15 per cent. of higher useful effect is all that can be claimed, when 55 to 60 per cent. is usual; but the advantage of obtaining at least twice the capacity, simply by enlarging the mouth and by increasing the number of blades to suit their reduction in length, is of high importance when room to place a fan in a building, is frequently one of the troublesome questions to be met. Since 1856 probably 150 of these fans have been put into use in various hospitals and public buildings. The principal modification adopted has been the frequent use of blades on both sides, with the same disc construction; sometimes (for fans of four to eight feet diameter) with iron in lieu of brickwork cases. This last arrangement presents some difficulties in the entering air passages, but it reduces the diameter of a fan to do any given work, to seven-tenths that of a single disc fan.*

* The only full published account of this fan is to be found in the proceedings of the Institution of Civil Engineers, 1869-70, but the publication in the catalogue of apparatus of the Pascal Iron Works, Class IV., 1863, and subsequently, gives essential particulars, and has perhaps much aided in the introduction of the fan. The catalogue was compiled by the writer of this paper.

In general these fans are driven by a directly connected engine of suitable size ; sometimes a belt and pulley is used for transmission from an independent engine. This last condition, that of independence from other uses, is desirable for hall ventilation, so that an economy of working may be practiced to meet the condition of occupied and unoccupied halls ; but for hospital ventilation it is about as well to drive the fans from the general source of motive power, always indispensable in large hospital establishments.

Boilers and all their appliances, engines, etc., are not distinctive or peculiar to ventilating or heating apparatuses, and call for no mention in this paper as to methods of construction.

The steam heating apparatus in all its details, as used in America, is peculiarly American, especially the apparatus of small wrought-iron tubes, which had its origin at the hands of the late Joseph Nason, between 1840 and 1850, and has now become one of the established industries of the land, employing a whole class of workmen known as steam fitters, and supporting large establishments, devoted entirely to the manufacture of and trade in tubes and fittings.

The little step in mechanism which is the foundation of this art, is found in the use of the tapering thread on the end of the pipes, wherewith a perfectly staunch joint is cheaply provided and made. It is curious, that with over forty years practice in steam fitting, until no workman in iron regards this taper screw joint as other than the matter of course way of making a pipe joint, with this established habit of workmanship, no description or notice of the tapering screw is published in any textbook, nor have its peculiar advantages been considered by any general writer on constructive mechanism. The great importance of this improvement in making the joints of steam pipes to this industry of steam heating can scarcely be over estimated ; but it was not only in this particular but in many others of detail, that Mr. Nason's ability as an inventor and adaptor was shown in the apparatus; while super-eminent above this he was at once the best informed of his day on the theory, and the most able in the practice of steam heating. Under his tuition the whole trade originated—ten or twelve years since it was possible to trace the descent or pedigree of any concern in the business to the original source—at this time, the growth of the business going to a third or fourth race of firms or of workmen, precludes the following out of the continuity, although it certainly exists. The business, however, has been, and is dependent

upon the development of mechanical ingenuity, mainly from Joseph Nason, who gave form to the globe valve, originated and derived or adapted from the practice of hot water heating apparatus in England—either the Perkins' high pressure or the green house low pressure system—all the essential details, which now form parts of usual every day construction in the United States. Curiously, steam heating as practised here, is not yet fully known or used in England or France, and but little more known in Germany.

The writer of this paper, became connected with Mr. Nason in 1848, when he was employed to superintend the construction of tube works at Malden, near Boston, for Messrs. Walworth & Nason, and from that time until now he feels able to claim some standing in advancing the industry of steam heating. It will have been noticed by most who have to do with construction, that the form and shape of valves, elbows, tees, and of details generally employed or made any when in the country, are strikingly similar. In fact they are universally copies, following exactly the designs and proportions, as to sizes and thicknesses, which the writer established and published in the catalogues of the Pascal Iron Works, nearly twenty years since.

From this general acceptance of the types of steam heating apparatus and its component parts, any one is at liberty to specify a definite construction of coils and mains, with a correspondence of detail. He can measure and plan to use any arrangement of standard articles, selected from any trade catalogue of a steam heating establishment or firm, and feel sure that the work will have been so arranged that it can be bid for in open competition, and that he is getting the best work or details of work, to effect his purpose in his own way. More than this, it may be regarded as tolerably sure that any patented improvement of detail or method, is inferior to what can be procured and supplied from regular traders.

In the arrangement of ventilating and heating apparatus for Halls of Audience upon the foregoing type, a few figures of proportions required may here be stated :

It having been accepted what number of people are to occupy a certain hall—taking the maximum number—the total quantity of air needed each minute, will be derived by a simple multiplication of this number by the quantity per person, per minute, which the occupancy of the hall demands. That is, for a hall occupied by occasional sessions of one or

one and a half hours, say ten feet, while for a legislative hall for frequent long sessions, thirty feet may not be too large, while proper judgment should determine intermediate values for other conditions of occupancy. The figures of total quantity of air needed each minute being determined, the sectional area of the duct, near the fan, is got by dividing this figure by 600.* Now, this area is simply that of the periphery of the fan multiplied by its width, and as the width of the single fan at the periphery is = one tenth diameter, it follows that the area of outlet is $= \pi D$ (= circumference), multiplied by $\frac{1}{10}$th D (= width) $= \pi D^2$ divided by ten. Taking the value of π (= ratio of circumference to diameter); making the division, and extracting the square root from the figures given, it follows that D (= the diameter of the proposed fan) = 0.073 times the square root of the number of feet of air to be moved each minute. This rule can be expressed more simply in algebraic characters, as follows:

$$Nq = Q; \quad \frac{Q}{600} = \frac{\pi D^2}{10}$$

Where N = maximum number of persons to be supplied with air for ventilation.

" q = least quantity of air per person, per minute, in cubic feet.

" Q = total quantity of air to be supplied, or the least quantity in cold weather, also in cubic feet.

" $\frac{Q}{600}$ = sectional area of duct near fan, in square feet.

" D = diameter of single fan, that is of a fan which carries its blades and receives its air on one side only, in lineal feet.

" π = ratio of circumference to diameter.

Reducing the above equation to give the value of D, then:

$$D = 0.073 \sqrt{Q}, \text{ nearly.}$$

and for a double fan or one receiving its air on both sides, then:

$$\mathfrak{D} = 0.053 \sqrt{Q}, \text{ nearly.}$$

When $\mathfrak{D}$ = diameter of double fan, or of one carrying blades and receiving air on both sides of the discs, in lineal feet.

The inlet or suction air duct or passage to a fan, should have, as an absolute necessity to supply the air, 1.4 times the area of the outlet or distributing duct. To compensate for resistance of air in passage along the ducts and yet to preserve the smallest efficient areas of distributing ducts

* 600 feet having been stated previously as the desirable rate of flow of a forced current in a duct per minute.

and branches, the sectional area of such distributing ducts or branches, at any given distance from the fan, should be increased over what is derived from $\frac{Q}{600}$, by adding 0.0025 times ($\frac{1}{400}$) for each foot of distance, and there is required a constant addition of 0.25 ($\frac{1}{4}$) a square foot, which becomes a necessity to meet the great resistance of small passages. The area of a main duct at any given distance from the fan, should be formed by computing after this method—the area of *each* branch, which may be considered as *trumpet shaped or expanding from* the fan to the point of bifurcation (from which point the *branch* may be deemed parallel), and this area is to be used when summing up an aggregate of total area of cross sections at such distance.

It may be needful to call attention of those who may plan a ventilating apparatus, that the air-ducts must be exclusively devoted to their purposes and should not be used, or even made so as to be available for passages. They may be employed for the lines of supply or return mains or distributing pipes, but the ducts should not be encroached upon by coil chambers constructed within them. Clear, unobstructed, smooth passages, with all angles rounded and all corners filled in, and all enlargements avoided, should present the least of resistance to the flow of air.

The foregoing formidable array of rules and data have been presented of necessity, for guidance in construction. They represent absolute and unalterable conditions in forced ventilation, and will enable any one to design, without mistake, when engaged in making original plans. It may be objected that the dimensions of ducts obtained by these rules are excessive, nearly to the point of impracticability, but in reply to this it must be stated that they (the dimensions) are less *by one-half* than can be employed for ventilating by heated currents alone (which is cold weather ventilation only), or for ventilating by exhaust shafts, heated in same way to induce currents (which is closed window ventilation). The frequent assertion of success of self-acting (as they are called) ventilating apparatus, often confutes itself, when the incompatibility of size of ducts is investigated.

As to the methods of distribution of currents from the branch ducts within a hall, and amongst an audience, the subject would call for longer discussion than there is room now to consider. It will only be said that at the mouth of discharge of each branch, baffling boxes must be arranged and provided, so that the afflux shall take place from an extended sur-

face, at a not greater velocity, within one foot of the surface, than two feet per second. A condition which calls for the area of surface to be ten times as great as the sectional area of the branches. And it is further required that the direction of afflux should be *upward* in general, or when horizontal it should meet some other current of afflux near by, and be directed upwards. The augmented current of afflux in horizontal directions, as in the risers of the seats or steps of an amphitheatre, is sure to engender local currents of much greater intensity than the original ones, and to become seriously objectional to an audience.

Whatever be the dimensions given to the supply ducts and passages, it must be remembered that those for removal of air must have adequate size, and if economy in the impelling force be studied, must be at least of equal dimension. In cold weather, with a high building—and all buildings are more or less high—the labor to be performed by any ventilating appliance in inducing a flow of air, is materially reduced by the ascensive force of the columns of hot air in the building. As the weather becomes warmer, more and more motive power is demanded to impel the current, but whatever motive power be expended, the movement of any quantity of air will cost in motive power as the square of the velocity. The supposition of any change in sectional areas (omitting some frictional considerations), which shall reduce them below the area accepted as the least at the fan, admits of a reduction of the fan itself to conform.

A thoroughly arranged ventilating apparatus calls for distributed removal of air as positively as it does for distributed supply, and for complete efficiency, all flues and branches of efflux should have, after providing the branches, similar baffling mouths to those described at mouth of entry, 1.4 times the area of the supply flues and branches.

With a forced ventilation, these flues should not have that compensation in reduced area, as they become high, which is essential to self-acting hot air shafts. The condition of ventilation assumed, supposes the expulsion of larger quantities of air, as the relative temperature inside and out, becomes more equal, and at the point of equality, the value of the height of the building as a shaft becomes nothing.

This large size of flues of efflux opens another source of trouble. It is almost indispensable that all the eduction flues shall be gathered into one single main flue, with judicious arrangement of the branches at their points of junction, so that they shall *direct* themselves into the general

current of effluent air, and entirely and completely fill the great flue or shaft, thus preventing any eddies or back currents from establishing themselves, from room to room, from one part of a room to another; or worse yet, from the outer air down one side of a main shaft and up the other. With numerous ventilating flues or chimneys to open fire-places in any one building, whether supplied with air by forced ventilation, or by any other ventilation, or if unsupplied with air altogether, but merely furnished with *ventilating flues*, or yet again, where numerous chimneys only exist, *the chance for a down draft* for some of them goes beyond the theory of chances, and becomes a certainty.

At all events, for a hall, the ventilating branches must be gathered into one general eduction shaft, while it may be possible for separate rooms to have separate, independent ventilating flues, with a little possibility of most of them working the right way, if the weather is not very cold.

A few figures of the proportions of steam heating apparatus, in combination with ventilating, may be given. In most buildings to be ventilated, as halls, there will be found rooms and passages, whose requirements in occupancy will demand a much less liberal supply of air than the halls, or session rooms themselves.

The quantity of air supply to such buildings will be derived from two systems, whilst additional heating capability will be required from a third system. The system dependent upon ventilation of session, audience or largely occupied rooms, has been discussed already, but the least quantity for occasionally occupied rooms is much in excess of what is needed, where the heated air is made merely the vehicle for transporting heat to a room to be warmed. The temperature of currents for ventilation solely, can scarcely exceed 70 to 80 degrees in the coldest weather in the most exposed hall, while rooms warmed more economically with smaller quantities of air, may have hot air currents of perhaps 110 degrees from steam heated surfaces. In the second case, the volume of air requisite will be found by deciding on the extent of heating surface for a given room of given exposure of outer wall, and position in the building. This extent of heating surface may vary from 1 square foot to 40 cubic feet of space in the room, to 1 square foot to 120 cubic feet of space in the room. The latter value representing a room of ordinary living size, with the least usual wall or window surface, sheltered from cold winds, and in the second story of a warmed building ; while the former value is that of the exceptional case of great exposure, or of

situation on the ground floor of the building. When an allowance for these circumstances has been made, and the quantity of heating surface needed for heating any room by indirect heating (as it is termed), has been reached, it may be accepted that 3 cubic feet of air per minute must be given to each square foot of heating surface, as the greatest quantity when the thermometer is at zero, at such time as the least supply for ventilation is supposed. A square foot of steam heating surface, with steam at 30 to 40 pounds pressure may be taken, *if well exposed*, to be capable of heating 3 cubic feet of air from zero to 100 degrees, or 5 cubic feet of air from 50 degrees to 70 degrees (or 80 degrees) in a minute.

It will be noticed that the heating capabilities of surfaces is referred to the cubic space in the building. The great loss or transfer of heat in any building takes place at the windows, so great that the computation might almost be confined to their surface as a unit to estimate on, and the surface of the walls or the cubic contents of the rooms be neglected. But, on the other hand, it is the *exposure* of the window which becomes of most account, and that has to be allowed for by judgment, and not by estimate, and with *exposure* a wall may become, if thin or thick, a material element in consideration.

Finally, the windows do bear a definite proportion to cubic space, or, if they do not bear the usual proportion, they may be *allowed* for ; until the skill in guessing comes back to a guess based on cubic contents, as equally valid with one based on window surface.

The third system of steam heating which finds examples in all large buildings—in passages, at or near doorways, or invariably somewhere—is direct heating by coils placed in the rooms to be heated. For this method there is demanded 1 square foot of heating surface for each 80 cubic feet of space within the walls of an exposed room, or of a room where the heating is demanded at short notice; as in an office which is allowed to become cold at night. While 1 square foot of direct heating surface is ample to warm 200 cubic feet of space continuously, without intermission day or night. Special demands to heat doorways and open passages, must be estimated on special grounds.

For heating in chambers with indirect heating (ventilation) box coils, as they are denominated, are best, while for office heating, vertical coils are decidedly preferable, although their surface is not so effective as that of horizontal pipe coils by about 20 per cent.

The main pipes for steam and return connections, by branch or direct

mains to each cluster, coil or radiator, should have the equivalent of 1 circular inch of sectional area for steam (or flow) connections (equal to 1 inch steam pipe nearly) for every 500 square feet of effective steam surface, augmented or enlarged 0.0025 ($\frac{1}{400}$) times for each foot from the point of first distribution or branch from the main. The condense water or return connection will follow the same rule, with the equivalent of ½ a circular inch for the same surface (equal to a ¾-inch pipe nearly). The aggregated area of great mains need not be so large as would follow from aggregating the branches, but should be increased in size up to the point of any branch, as if the enlargement of that branch, for distance, occurred at the point of branching, and not at the coil or heating surface. This rule will, if carefully read, prove easy to apply.

Flow mains should rise to some point (where they can be trapped or drained), vertically, and then have a descent of a ½-inch in 10 feet, regularly, to the end. If circumstances do not allow this, steps of vertical rises, well trapped, should be succeeded by lines of descending grade. The return main should have a corresponding fall towards the boiler, or other condense water recipient.

Boilers of the common tubular form require about 1 square foot of boiler surface (reckoning all the surface, of whatever kind, exposed to the fire or to the gases of combustion, between the grate and the boiler chimney), to each 9 square feet of heating surface in coils or radiators.

The grates of such boilers should have 1 square foot of surface to about 30 square feet of boiler heating surface. These ratios give 1 square foot of grate to 270 of radiating surface.

The chimney flues for the boilers (the stack) demand a sectional area from one-tenth of the grate surface, for chimneys of 50 feet high, to one-twelfth of the grate surface for chimneys of 100 feet high. These last dimensions are smaller than customary, but sufficiently large if no further requirement will ever be put on the apparatus.

The maximum quantity of coal to be consumed on these grates will not exceed 8 pounds per square foot of grate per hour, while the average quantity will not be over 20 to 30 pounds of coal per square foot of grate in 24 hours for 6 months of a year. A fan delivering 20 000 to 40 000 cubic feet of air per minute, will demand from 20 to 60 lbs. of coal per hour to supply steam, as a rough estimate.

In planning boilers, it is usual to allow one extra boiler for contingencies. There is no necessity to estimate on the supply of steam for

the power needed to impel the fan, where buildings are warmed and ventilated, as the exhaust steam of the engine should be utilized for heating purposes, and little extra steam is demanded for this purpose of driving the fan, so little, that the quantity may be neglected in the total of allowances for successful warming.

Further discussion might be had into the mechanical details, constructively, or as to either their ratios to the great units of individuals to be supplied with air for ventilation, or of cubic space in buildings ; of some possible interest to the construction of apparatus ; but my purpose has been only to give such figures and data as are indispensable for arranging the ventilation of halls of audience. Every word of superfluous description, and each extra figure, has been carefully eliminated, with the sole view of making this information complete in its ostensible direction. The paper, however, cannot properly be concluded except by calling attention to some requirements, that seem not to have heretofore been adverted to by other writers, but which really control the working of any apparatus, for either warming or ventilating, or both, and which call for modifications in arrangement and construction, almost amounting to a novel system.

The temperature of steam heated surfaces, for steam of such pressure, as is usually carried in heating apparatuses, where the boilers furnish steam for running the fan engine, that is, at 40 to 60 pounds pressure, will run from 290 degrees to 310 degrees; and these temperatures are practically uncontrollable whenever the steam is admitted to any coil or radiator ; so that the external surface of the coil or radiator in air is sensibly the same, 290 degrees to 310 degrees. Some slight but unreliable reduction of temperature in the steam, may be had by throttling the supply pipe, but this method becomes especially unreliable when the condense water is returned, without trapping, at the same pressure, to the boiler. Coils give off heat determinately until the last moment of being shut off. They fill with water, and become very noisy with water hammers; when a small volume of steam in someway is interposed between two columns of cooled water that instantaneously condenses it and forms a vacuum, bringing such columns into solid contact with each other. In exposed places throttled coils freeze up. The nicest adjustment may secure the end of lower temperatures of surfaces, and corresponding lower temperatures of air currents passing them ; or of desired constant temperature of air current, obtained by giving less heat to a warmer en-

tering air; but the least change of boiler pressure disturbs it all; in a moment the coil is virulently active with heat, or obstinately passive by water clogging.

There are two methods of meeting this difficulty. The first is the division of a coil into sections, so that one or more of the sections can be employed in heating or be shut off at will.* Some person in control of the apparatus, or at least of the coil for heating, will thus have the means at his disposal to produce any wished for temperature, down to the temperature of the outer air. The second method is found in passing around the coil, unwarmed, such part of the current of entering air as will reduce or temper down that remainder of the current which is permitted to pass through the coil, and is heated by contact with the heated surfaces. A comparatively simple arrangement of the casing of the coil, with register or louvre (blind) valves, and some baffling contrivance to secure the admixture of the two currents, is the mechanism of this method, which, as a method, is nearly as efficient as the former one.† In one essential regard it is more efficient, that is, the by-passing method gives an instantaneous change of temperature of the air delivered in the rooms, while the sectional method calls for time to elapse until the closed-off sections shall have lost their heat, or the newly opened ones increased in temperature, before any effect is produced on the temperature of the air.

It now becomes proper to remark upon the great general cause of failure of the well planned, thoroughly constructed, and entirely controllable apparatuses for heating and ventilating. Anomalous or paradoxical as it may sound, it is a fact, that the most complete apparatus may be the *most* perfect failure. Every improvement in mechanism may have been schemed, every contingency of working may be adequately provided against, and yet the accomplishment, in warming and ventilation, will have resulted disastrously. The fact is certain, and to what fundimental error can it be ascribed? The mistake can, in my mind, be traced to the assumption, upon which the operating of apparatuses have been universally based, *of control* of the individuals warmed or ventilated,

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* In the heating apparatus constructed at the U. S. Capitol in 1855-6, this method was introduced by Mr. Nason, and the complete control of temperature, in cold weather, for any given supply of air in every room in the building, was given to the engineer or his assistants.

† This arrangement, which was suggested by Mr. Faber du Faur, was introduced in one instance at the U. S. Capitol in 1858, and was entirely successful in the attainment of its purpose.

as regards their sensations of comfort, or their requirements for health. The error lies in giving the regulation of temperature to an engineer, or even to a general director (in case of an important building). An engineer may be a thoroughly competent mechanic, even more, he may be well informed in the practice, and possibly in the theory, of heating or ventilating. A director may have the theory and practice of heating and ventilating at his command, and be eminent in science or medicine as well, but from either of these, control will be resented, and any effort to enforce needful authority will be thwarted. If this be the condition of operating an apparatus in competent hands, what happens when those less likely to enforce authority are placed in charge? The usual engineer is a well taught mechanic, with ability to run and keep in order an engine, to direct the fireman, and possibly able to do his own steam fitting in repairs; one who in the pride he would take in a well kept apparatus, beyond the keeping of which he has no ambition, commands respect in his vocation. For such an engineer the capability cannot be expected which would allow him to direct or deviate when differing requests are made.

Any man may warm himself as he pleases. It is impossible for a number of men to tell one man what will please each of them individually, and for that one man to please them all. It is not the provision of means of control that will secure the wished for result. With every appliance failure is certain, unless those appliances pass into the hands of the persons to be warmed themselves. The neglect of this essential condition has led to repeated failures, until there is a popular belief that no ventilating apparatus can be successful, and there exists a general preference either for direct steam heating; where an occupant of a room can manipulate the cocks or valves to his own liking, or for mere current warming; where opening or closing a register, also by any person in the room, controls the heat supply satisfactorily, when no importance is attached to the air thus adventitiously furnished or closed off. Only hospitals, or jails, or orphan asylums are happily ventilated, regardless of the volition of the sufferers, but greatly to the delight of ventilation doctors, whose experimental results are pleasant to contemplate.

While commenting thus freely upon the drawbacks of previous efforts, it is a suitable requirement upon the fault-finder that he should offer a remedy; and a remedy will now be proposed, which is: That to the engineer, or persons in charge of the apparatus, should be delegated the

running of the same mechanically, in a defined way, without his or they assuming the regulation of the temperature of comfort in any room or hall; or part of a room or hall, where the magnitude of the same admits of division into parts. The temperatures desired or attained being positively controlled, within certain limits, by the occupants, or by representatives of the occupants, such as floor officials or ushers, in the rooms or halls. The limits of temperature proposed are 50 degrees for the lowest and 80 degrees (possible) for the highest. The supply of air at any one time should be constant and invariable, so that the equilibrium of distribution, will not be disordered by the closing-off or wide-opening of registers for admission of air—the usual process for controlling temperatures with heated currents at present.

The arrangement of apparatus to effect the foregoing, becomes necessarily a matter of original plan and construction, and is as follows: The boilers, fan engine and fan may be assumed, for convenience of running, as well as for better and simpler construction, to be placed in juxtaposition in vaults, at any desirable point about the buildings or grounds. Where the grounds near the building fall away, so that the boiler can be located above ground, and yet below the levels of the coils, this disposition of boiler is preferable. One of the advantages of the proposed method is, that except the cost of ducts and mains, the placing of boilers some distance from a building, say some 300 or 400 feet, is not objectionable.

When the desirable level for the boilers, with regard to the coils, for direct return of condense water without force, cannot be had, the return mains can descend to some separating recipient, where the condense water can be trapped-off to a hot well from which the boilers will be fed by a pump; or the coils may be trapped separately or in clusters, and their condense water taken by return mains to the hot well; or the coils may be trapped-off, and the hot condense water wasted; or yet, again, the return mains with regular descent may carry the condense water to a *closed hot well*, placed below the boiler level, under the boiler pressure, from which it will be elevated by a *closed pump* to supply the boiler.*

The main duct should be dry, air-tight, and closed as a passage way, absolutely without openings into rooms, vaults, or general passages, ex-

* This last very valuable improvement in the arrangement of return mains was proposed and introduced by Wm. E. Worthen, M. A. S. C. E., of New York. It presents the same advantages, as regards the " air difficulty," that is found in direct return to the boilers.

cepting only such doors as may be necessary to give access to the duct for the purposes of the apparatus. Every precaution should be taken to make the main duct *inconvenient* as a thoroughfare. This main duct, in the arrangement of apparatus here proposed, may be carried under ground or under floors, anywhere amongst the foundations or cellar walls of the building; only prescribing that it shall be well built in smooth finished masonry, without angles, dry, air-tight and closed. Ducts smaller than twelve square feet sectional area, may be built of thin galvanized iron, or may be built of wood (with narrow, 3-inch wide boards, tongued and grooved, mill planed both sides), and lined with light sheet tin, with soldered joints. The wood work of ducts need not be expensive, but it should be substantial. While small ducts or branches can be cheapest made of thin galvanized iron, in permanent structures, brick work ducts, with arched or slate covered roofs, of all sectional areas, branch ducts included, is the best construction. Coil chambers should be built in the manner and of similar materials described for ducts.

Returning to the arrangement of apparatus: There is to be constructed either directly in advance of the fan chamber or close behind it, connecting to the main duct, an *auxilliary coil chamber* to hold an auxilliary heating coil. This auxillary heating coil should be built in at least four separate sections, (with perhaps a larger number for an extensive apparatus); and this coil should, in its aggregate of surface, have enough to heat the entire volume of air required for winter ventilation from zero (or from the supposable lowest temperature of winter) to 50 degrees. Besides this sectional arrangement of the coil, it (the coil) should be so placed in the coil chamber, that the air can be passed or by-passed, through or around any one or other or all of the sections, under the regulation of sliding doors or of louvered blinds, so that not only complete but instantaneous control of the heat of the entering air can be had.

With the use of these means of control of the heat of the air entering the ducts, to meet every temperature of the external air, the duty of the engineer so far as relates to the *heat* in the building (for the most part) ceases. He will be required to see at all times, when the outside temperature ranges below the limit of 50 degrees, that the air passing into the main duct has a constant temperature of 50 degrees.

This temperature offers great advantages in the transmission of air

currents. It allows them to be carried under ground, in cellars, near foundations and under floorings, to any desirable distance, without loss or gain of heat in the transmission. It places all the local coils in the building on an equality in the demand upon them to supply hot or heated currents. It will be found that half the heating surface for the entire building will be demanded in this auxilliary coil, and that this surface will be peculiarly efficient, because of the great difference between the temperature of the coil surface and that of the effluent air from the coil. With the reduction of dimension of the local distributing coils, a corresponding reduction of dimension of flow-and return-mains will be permissible. And an advantage of the highest importance is yet to be stated; all risk of freezing up the return mains or the lower pipes of the local coils (or occasionally an entire coil) is obviated, while nothing but positive neglect, could allow freezing to occur in one of the sections of the auxilliary coil.

The local distributing coils should, perhaps, be sectional, in not more than two sections for the larger coils, but it is questionable whether any division of these may be necessary, although the writer would advise it in construction. These coils should be in chambers arranged for the air to be passed or by-passed, through or around them, by the regulation of slides or valves *to be placed under the control of the occupants of the room or of the officers or ushers in a hall.* The means for regulation should be solely in the rooms or halls, themselves, and any gradation of temperature of entering air from 50 degrees to 80 degrees, should be instantaneously commanded, without, however, varying the quantity of air regularly supplied. If, with these provisions, by any accident or neglect the extreme of heat or of cold be allowed in the air supply for a short time, the effect will not be serious, for the instant restitution, to what the occupants of a room may deem their temperature of comfort, is feasible. The settlement of degrees of discomfort amongst the number occupying a room, will have to be effected by tolerance, much as the fresh air is got in a railway carriage, where there is no one to blame but the passenger when a window is opened or closed.

In halls it is manifestly proper that the floor should be separated in divisions, each having its own supply of air, so that the local regulation may meet, not only the small differences of local requirement which always occur, but also the differences of individual demand of equally general, and even more urgent occurrence. The galleries of halls have

not merely a small difference in requirement, but at all times they demand two or three or even more degrees *less* temperature for entering air than the floors. In some cases, as in the Senate Chamber or the Hall of Representatives at Washington, and generally in all legislative or council chambers, the galleries are occupied by a crowd of spectators clothed, in cold weather, in heavy outer garments, while the floors must be comfortable for the members, who are by no means crowded together, in usual indoor clothing. At evening sessions when gas lights are required, the increase of temperature therefrom will be found mainly in the galleries, and it then becomes essential to supply them with cooler air than the rest of the hall. It is a consequent necessity for the successful ventilation of halls, that the gallery supplies of air be distinct and separate from those to the floor; and it is much better to arrange for these supplies in separate divisions, one, if not two, to each side of the hall.

The duty of the engineer of the apparatus, so far as the local coils is concerned, will require him to put in use one or both sections of such coils to meet the demand of the season or day as regards mere warming and positive heating. Beyond this he has, whenever the external temperature is below 70 degrees, only to see that each coil is supplied with steam, and in satisfactory operation as a steam coil, under full boiler pressure. With this, and with his charge of the temperature derived or proceeding from the auxilliary coil, his responsibility for heating the building in cold weather ceases. As the weather becomes warmer in any year, and when the external temperature reaches 50 degrees, the auxilliary coil is thrown off. At 65 degrees to 70 degrees the local coils cease to be operative, and thereafter the engineer, running the fan at double rate when summer ventilation is required, supplies to such hall, (the ventilation of which was based on ten cubic feet of air per person per minute), the maximum of twenty cubic feet; which quantity will be found nearly all that can well be delivered amongst a crowd, where each person occupies, say four square feet of floor space, or the average theatre allowance.

Economy in running an apparatus, must always be considered in planning the same, and no building can be *ventilated* to the full extent continuously, whether its hall be occupied or not, with any proper regard for expenditure. It follows that notwithstanding what has been said about exonerating the engineer or director of the control of the heating,

there must yet be left, with these persons or one of them, the means of reducing the air supply to meet the real necessities of use or vacancy—of complete or partial occupancy. This may be effected in part by the running of the fan, but it will be found necessary to provide for regulation of air delivery by closure of ducts or branches to some extent. As the local coil surfaces are unalterable, the effect of employment of a greatly reduced volume of air at times, will be to enable them to give currents of much higher temperature than 80 degrees.

Thus in a hall with 1 200 people, at a minimum of 10 cubic feet per person per minute, we have 12 000 cubic feet per minute. If the local coils can take this air at 50 degrees and heat it to 68 degrees, which may be supposed to give 70 degrees in the room in moderate weather, and if the same local coils can take this air at 50 degrees and heat it to say 75 degrees in the coldest day (the 80 degrees heat from local coils is supposed in this case to warm up the room after it may have been chilled for want of heat), and also to give 70 degrees in the room ; it is evident that reducing the quantity of air to 1 200 cubic feet per minute, these same local coils are sufficient in extent to carry the 1 200 cubic feet from 50 degrees to over 125 degrees in the same minute of supply, and at this temperature the room will be warmed to 70 degrees against zero out of doors, at greatly less expenditure of fuel. For in one case there is wasted of vitiated air, 12 000 cubic feet which had been taken at zero and allowed to escape at 70 degrees, while in the other case, only 1 200 cubic feet, taken also at zero and escaping at 70 degrees, is demanded in effecting the heating.

This possiblity of economizing in the working of every system of ventilation is the bane of all methods. Ventilation is not economic as a process of warming. In many instances after a demonstration of successful ventilation, the working of the apparatus is permitted to degenerate to the barest warming. There is demanded a conscientious persistency in maintaining a thorough ventilation, where the warming can be made satisfactory without it, that surpasses the moral appreciation of a money-getting manager or of an economic official.

In presenting this optimist view of the subject of practical ventilation of halls of audiences, it must be accepted as indicating the path of advance, not as demonstrating the impropriety of advance. No expenditure is justifiable which cannot have the assertion of necessity, nothing surpassing the admitted wants of society will be appreciated or

willingly paid for. The current belief and faith in the necessity for purer air in halls, must be entertained by the audiences, before the expenditure for provision or of maintenance of ventilating apparatuses can be warranted. It is sure that people do become less tolerant to the closeness and odors of halls, court rooms, school houses, year by year. This is evidenced by the extravagant schemes of sanitation of such places on the one hand, and by the boasts of impossible accomplishment with wholly incompetent means on the other, that find so frequent publication. It has been the purpose of this paper to set forth the least quantity of air supply, compatible with relative purity in the air of an occupied hall, and then without gloss or extenuation, to set out the difficulties and costs in obtaining this least quantity, and the inconvenience and discomfort attendant, so that they shall all be appreciated as incident to the problem of ventilation.

Above all, in the effort to give or establish practical limits for the necessities of ventilation in halls of audiences, which can with safety be aspired to at this present time, and with justice be demanded by the community from all those who control the management of audience or session rooms, it is not wished to be misunderstood by supposing that this paper has been or is, advocating the dispensing with any real demand in quantity or quality of the supply of fresh, pure air. Compliance with the present *system of ventilation* of hot air furnaces, which *system* is merely heating to requisite intensity, with adventitious supply of air, is as far from the ideal of perfection, as the scheme of giving to the occupant of a hall, the healthful air of the mountains, with the freedom and volume of the west wind, is from the possibility of construction or of operation. Little by little modern society appreciates the conditions of healthful, civilized existence. The removal of cause of offense is the first requisite of sanitation, and it is the first requisite of ventilation. Our tolerance of personal uncleanness in small ways, and in large ones also, goes far to account for the offensiveness and unhealthiness of many places of public gathering. Arguments on this point, and social enforcements of regulations in this regard, in theatres, court rooms, galleries of public halls, school rooms, public conveyances of all kinds (especially the latter), will be more efficient than the indoctrinating of surmounting the difficulty by gales of fresh air, funished regardless of comfort and of expense.

Finally, after establishing the *requirements* for necessary and indispensable ventilation of audience halls and of audiences it becomes

the indispensible preliminary, that the original planning and subsequent erection of the buildings shall provide suitable rooms for apparatus, together with ducts, distributing passages and flues, in order to render available the methods of the mechanical engineer; by which methods ventilation, with comfortable heating, can now be effected with controllable, positive and satisfactory result.

Addenda.

FANS.

Data relating to fans for ventilation, to be used in preparation of plans of buildings.

The following illustrations, together with a table of practical data, have been taken from the paper, "On the conditions and the limits which govern the proportions of Rotary Fans," read before the Institution of Civil Engineers, London, in 1870. This paper was offered to the Institution by the present writer. As before stated, this fan construction offers the advantage of giving the least possible dimensions for the performance of a given work, in the movement of air. To some the sizes of parts of the fan, or of the air ducts, may seem large; but when the quantity of air is fixed, the economy of power demands low velocities and pressures in the ducts, so that large ducts and large fan mouths become necessities.

The sections and elevations, Fig. 1 and Fig. 2, show a double fan, that is one receiving air at both sides, through openings in partition walls, and delivering it at the periphery, into the space enclosed by the partition wall, from which space the air passes to, or enters the duct. The arrangement and construction of a single fan supposes a *half section* on the line of the disc, to represent a complete section of the single fan. These views show a sheet-iron ring, a piece of a cone attached to the mouth piece, as forming the sides of the fan. For single fans it is not unusual to form this side in a splayed ring of brick work. The fan illustrated is, as the scale shows, of 10 feet diameter. The fan shaft, whether for single or double fans, should have two bearings immedietely near the fan, in each mouth, as shown in Fig. 1; or in case of a single fan, one bearing in the mouth, and the second, on a back pedestal behind the fan; and besides these there must be a third bearing, to which the shaft extends, near to the driving pulley or the crank, from which the fan receives its power. The shaft should be long enough to allow the pulley or the engine to be located in a room separated by a partition from the passage for air, in entering or passing from the fan. Damp air being destructive of belting, and an engine room in a gale of wind, and practically out of doors, being manifestly an unsuitable arrangement.

Figs. 3 and 4, give the constructive diagram for fans of the type suggested.

EXAMPLE OF GENERAL DIMENSIONS OF A FAN OF 10 FEET DIAMETER.

PLATE V.

Fig. 2.

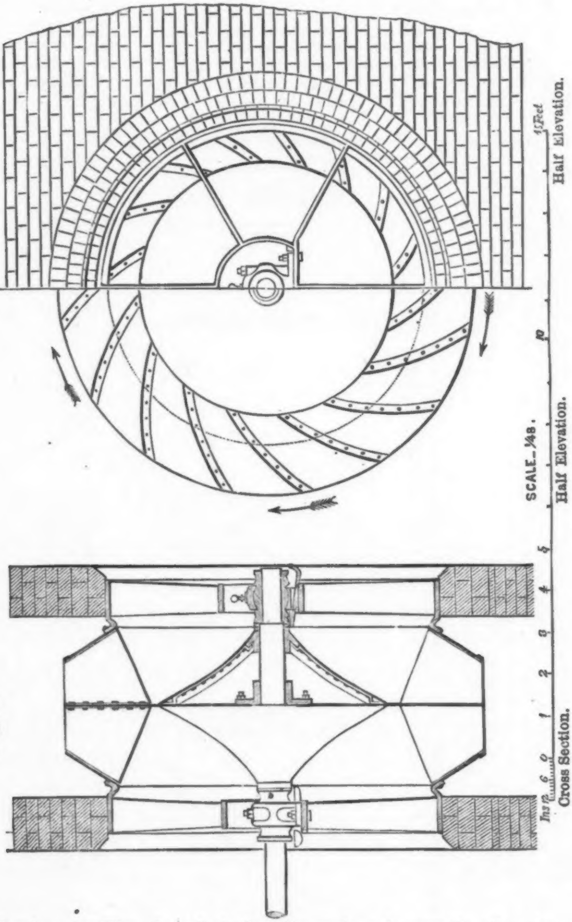


Fig. 1.

Referring to Figs. 3 and 4 the dimensions in practice then become when R = unity

A	= radius of inlet	= 0.742
B	= width of inner edge of blade . . .	= 0.35
E	= " outer " " . . .	= 0.2
C	= " zone of blades on disc . . .	= 0.4
F	= " " " on case . . .	= 0.258

K = face of curb in front of disc . . . . = 0.373
L = place of centre line of pedestal in front of disc . = 0.5+0.08 ft.
D = radius of shaft . . . . . . = 0.046
G = " hub . . . . . = 0.075
V = " contour of cone . . . . = 0.94
W = locus for centre of **V** in front of disc . . = 0.92
X = " " " " from centre of fan . . = 0.829
Y = radius of loci of centres for generating curves for blades . . . . = 0.844
Z = radius of generating curve for blades, approximate 45° logarithmic spiral . . . . . = 1.194

PLATE VI.

Fig. 3.

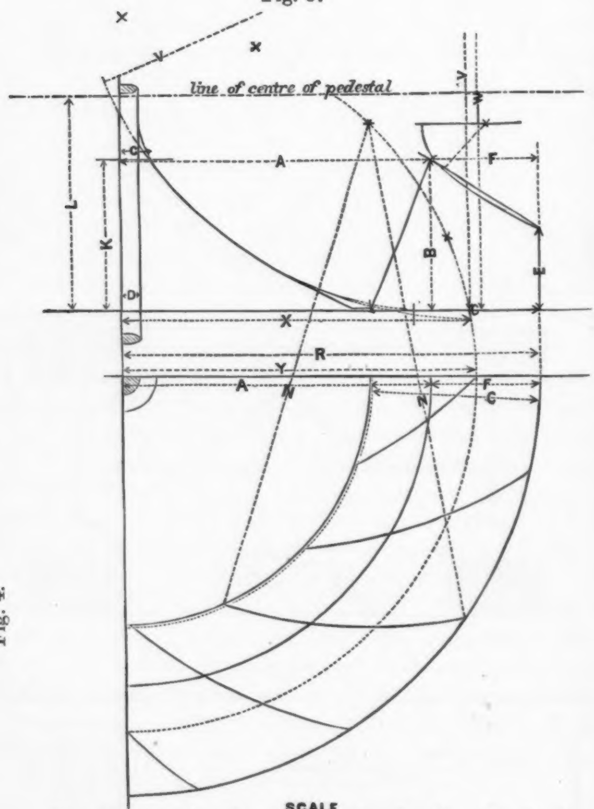


Fig. 4.

Fans to be Used in the Ventilation of Buildings.

Diameter of Fans.	Revolutions per Minute.	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure.*	Pressure, difference between inlet and outlet of Fan, corresponding to Number of Revolutions taken.*	Horse Power required to deliver the quantity of Air at given pressure.	Dimensions of Pulleys.** Number of Pulleys.	Dimensions of Pulleys.** Diameter of Pulleys.	Dimensions of Pulleys.** Width of Belt demanded.	Proper Sectional Area of Delivery Air Duct, or Passage.***
Ft.	Number.	Cubic Feet.	Water Column In. dec.	H. P.	No.	Ft. In.	Ft. In.	Square Ft. dec.
16	62¼ to 125	102 500 to 205 000	0.31 to 1.23	7½ to 59	2	8 4	1 3	160·8
14	70 " 140	80 000 " 160 000	" " "	5¾ " 46	2	7 6	0 10	113·2
12	83 " 167	57 500 " 115 000	" " "	4⅛ " 33	2	6 9	0 8	90·5
10	100 " 200	40 000 " 80 000	" " "	2⅞ " 23	2	5 2	0 6	62·8
8	125 " 250	25 500 " 51 000	" " "	1⅞ " 14¾	1	4 0	0 8	40·2
7	140 " 280	20 000 " 40 000	" " "	1½ " 11½	1	3 6	0 6	28·3
6	167 " 333	14 400 " 28 800	" " "	1 " 8¼	1	2 8	0 5	22·6
5	200 " 400	10 000 " 20 000	" " "	¾ " 5¾	1	1 10	0 5	15·7
4	250 " 500	6 400 " 12 800	" " "	½ " 3¾	1	1 4	0 4	10·05

* Double the quantity of air will be delivered each minute if the resistance to discharge or suction is brought down to one-half the pressure given in the pressure column, and the pressures may be increased (the number of the revolutions of the fans remaining constant), by closing partly the inlet or outlet, the quantity of air delivered being gradually diminished until the inlet or outlet be entirely shut off, when the pressures will have risen to double those stated in the table.

** The dimensions of pulleys and belt refer to the largest capacity of the fans given in the Table, it being supposed that it may be desirable to range from the lowest quantity and pressure to the highest in each case.

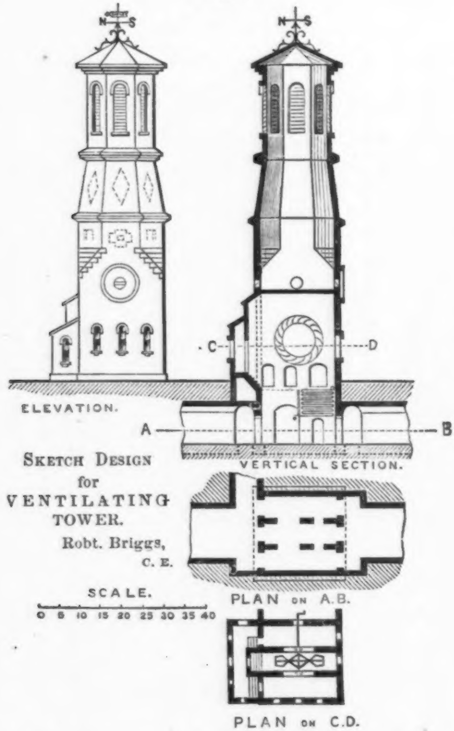
*** The sectional area of the inlet or suction air-duct or passage should exceed the area given by 1·4 time, to allow a fan to produce its fullest effect. It has been found, when it was inconvenient to make the air-ducts or channels of full sectional area to the end of a system of distribution, by enlarging them 0·0025 per foot of length, so that outlets and channels, at the distance of 400 feet, were provided with double sectional areas, that the falling off of pressure was satisfactorily compensated for, at the more distant outlet. It is obvious this rule will not apply to very small air-passages. When the relationship of quantity and pressure corresponds to that given in the Table, and it is never expected that a larger quantity will be required at a reduced pressure, the sectional area of the delivery air duct may be reduced one-half, or nearly to that extent. The sectional area given, admits the passage of double the quantity of air at one-half the pressure. The frictional resistances of the sides of a duct are so considerable, that the largest duct possible should always be used, even when somewhat in excess of the dimensions given as those desired.

VENTILATING TOWERS.

§ The sketch design of Ventilating Tower, Fig. 5, is not offered upon architectural merits, but to exhibit an arrangement of ventilating tower, together with a fan, auxiliary coil chamber and auxiliary coil, and with underground ducts. The question of the source from which to derive the *fresh air* for ventilation of any building, is a very difficult one

PLATE VII.

Fig. 5.



to determine. The propriety or expediency of a tower at all, or if at all, under what circumstances, is not definitely settled. In one regard, that

§ This sketch is derived from a study for the ventilation of a public building made some three years since.

the tower is a monument to ventilation ! there is a strong architectural basis for its employment. Quoting in the main, from a discussion of a tower in a previous paper of the writer.* The dimensions of a tower are fixed by the quantity of air needed, and they will be found to be very large ones. To supply, for instance, from 20 000 to 40 000 cubic feet of air per minute, the sectional area of the air passage in tho tower, ought not to be less than 40 square feet. In other terms, the velocity of air in the air passage of the tower, should be not over 1 000 feet per minute.

How high must the tower be, so as to find pure air uncontaminated from *all* impurities, or so as to find that relatively pure air which shall meet acceptation ?

Investigation upon the purity of air in different places and at different elevations, and at different seasons, have been repeatedly made, the result of which, as regards cities may be stated with brevity. "There are great variations in the quality of air in different cities, arising from relative density of population, nature of fuel, character and avocations of the inhabitants ; and again, from climate, prevailing winds, and winds at the time of observation, hygrometric condition, normal or abnormal, etc., etc., but after the dispersion of impurity generated in any particular locality, the purest air is to be found from 6 to 40 feet, and the most impure, 70 to 90 feet above the level of the ground; with gradations from 90 feet high, rising to balloon height. Over any free or open places in a city, the dispersion of local impurities is more completely effected, and the uniformity of condition more generally obtained ; but the elevated air is more impure, when the stratum of diffused chimney exhalations is reached, than it is below. The haze of any large city is perceptible for miles on a still day—the entire city is covered as with a blanket by an ascending and dispersing cloud, and receiving its fresh air from beneath from all sides."

In the country, and probably amongst vegetation in the cities, as in parks or squares, the air near to the ground may be considered as the most humid, and the most likely to carry or propagate organic germs. In fact, it seems an instinctive requirement that causes all mankind to choose the second floor, or other upper floors of dwellings as the proper dormitory level. So that the argument appears to favor the taking of air for ventilation, both in cities and country, at some point from 6 to 40 feet above the ground surface.

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* Rept. Vent. Hall Reps., 1876.

It may be remarked, that in large public buildings, where there is an enclosed court yard, not used by the travel of horses or animals, such yard is so repeatedly aerated by the removal of air for ventilation, as to become of itself a ventilating shaft, equal to any separate one that can be constructed. And it must also be noticed that the necessities of all buildings, as regards demand for fresh air, and their location or advantages in obtaining it, must determine the existence of a tower for air supply, as well as its dimensions. No tower is needed to obtain fresh air for the Mountain House at Mount Washington, not so much because of the elevation, as because of the local advantage of absence of sources of impurities.

ESTIMATION OF HEATING SURFACE.

§ The following gives an approximate estimation of the cubic space, in rooms or buildings, which can be warmed by a unit of steam-heated surface, placed in a chamber more or less remote from the room itself; the transmission of heat from the heating chamber to the room, being effected by currents of warmed air passing through flues.

The conditions upon which such an estimation is to be based are numerous, and it is here attempted to state them succinctly, if not briefly, as follows: The maximum temperature of the steam-heated surface is taken to be that derived from steam of 15 pounds pressure to the square inch, or 250° temperature of steam.* The surface employed is deemed equivalent in effective value for dispersal of heat, to that of plain cylindric surface in black, or unpainted, cast or wrought iron. Which surface may be considered to be typified by the ordinary "box coil" of one inch wrought iron pipe, not less than 10 pipes high, with air supply and delivery distributed by perforated plates, above and below the coil, into favorable contact with the pipe surface. Where other descriptions of radiating surfaces are employed precaution must be had to insure contact, as for instance, with plates or vertical tubular surfaces. While for plate surfaces having projecting ribs or pins, which may, in great measure, or entirely, answer the purpose of insuring favorable contact of the air with the surface, the efficiency of the superficies of the ribs or

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* As was stated when discussing the uncontrollable temperature of steam heated surfaces, the common temperature of steam in large apparatuses runs up to 290° or 310° = 40 to 60 pounds pressure. 290° gives a surface over 30 per cent. more efficient to heat air from zero to 110°, than 250°.

pins may (where some considerable thickness exists, to give conductivity), be reckoned as half that of the plain surface to which they are attached.

It is also prescribed that the flues and ducts for the passage of the currents of heated air shall be of ample and *proper* size, as established in the text of this paper; and that they shall be well guarded from loss of heat, and metal lined throughout, to ensure smooth channel-ways, and all angles must be formed with gentle curves. These conditions especially refer to heating by self-acting currents, where the flow is produced mainly by the levity of the warm currents together with that of the warmed air in the room.

Qualified in these respects, it can be accepted, for the climate of Philadelphia, where the minimum temperature for any whole day of twenty-four hours is not below zero, that 100 cubic feet of space in the average of buildings used as asylums or hospitals, or 80 cubic feet of space for the average of buildings used for offices, will be adequately supplied with heat by currents of air of the proper volume, passing over one square foot of steam heated surface. In these buildings it may be assumed that the management of the apparatus is in the hands of a competent fireman, and that the boilers are run as is usual for those of factories. For dwelling houses where slow and irregular firing is the practice, the ratio of space to heating surface becomes about 60 to 1.

This ratio of 100 cubic feet of space to 1 square foot of heating surface is stated to be an average one for an entire hospital, and must be apportioned to the several rooms, with corrections for exposure of wall or window surface to the external air; that is, with regard to the points of the compass to which the frontages refer; with corrections for the proportion of window surface exposed; with corrections for unusual height of stories; with corrections for unusual thickness of wall, or for peculiarities in construction or methods of prevention of loss of heat at the windows; and in the case of self-acting apparatuses or those without a forced ventilation, with allowances for the elevation of the rooms in the building. In fact this last allowance may be made in any case.

It will be first attempted to set forth a simple rule for the apportionment of heating surface. It is thought that the second floor or story of a building will represent the average requirements fairly; when the first floor will demand, approximately, one-ninth more heating surface, and each story above the second may be held to require one-ninth less heat-

ing surface successively. Perhaps this rule would fail with the fourth story, where the elevation would be likely to increase the value of the external exposure as the occasion of loss of heat.

For the second or normal story, the number of cubic feet to be warmed by one square foot of heating surface becomes, for rooms facing as follows:

North = 80 cubic feet.	South = 120 cubic feet.
N. E. = 90 " "	S. W. = 110 " "
East = 115 " "	West = 85 " "
S. E. = 130 " "	N. W. = 70 " "

Average space per square foot of surface for the second story = 100 cubic feet.

The values for the several stories may be tabulated as follows:

TABLE.

Stories...	1st.	2d.	3d.	4th.	Stories..	1st.	2d.	3d.	4th.
	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.	cu. ft.	cu. ft..	cu. ft.
North...	72	80	88	96	South...	108	120	132	144
N. E.....	90	90	99	108	S. W.....	100	110	121	132
South.....	104	115	126	138	West....	76	85	94	102
S. E....	117	130	143	156	N. W....	63	70	77	84

An approximate correction for extent of window surface may be suggested. A square foot of window surface may be taken as belonging to each 100 cubic feet of contents, of a room.

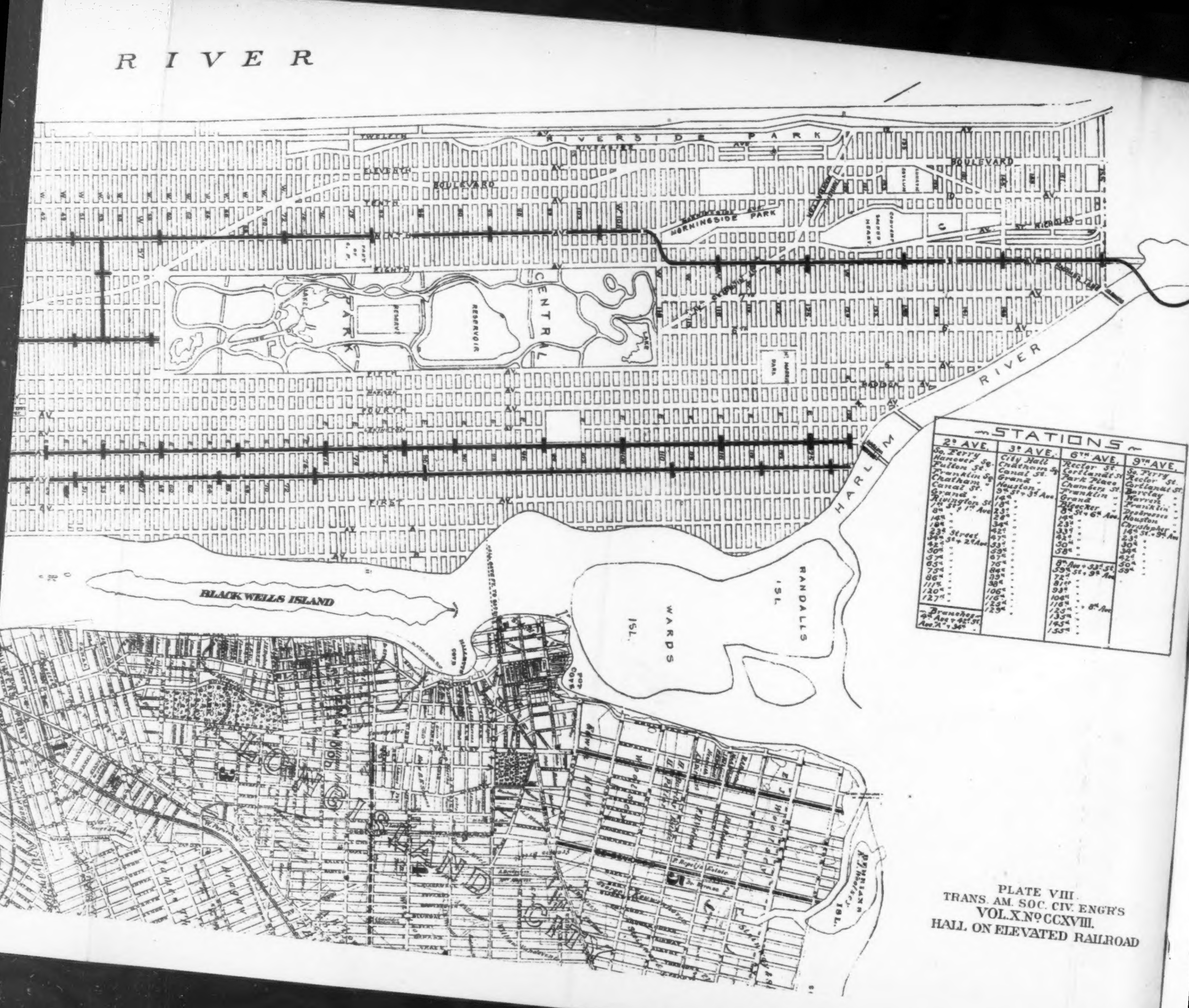
Having ascertained the excess or want of this extent of window surface in any room, one-half *the ratio* in excess or wanting to the (assumed) proper quantity may be taken as the dimunition or increment of the total cubic space for a unit of surface.

The other corrections suggested must be made a matter of judgment on the part of the person making the estimates.

REFERENCE—CONTENTS.

THE CITY OF
NEW YORK
SOUTH OF 155TH STREET.
SHOWING THE CONSTRUCTED LINES OF
ELEVATED RAILROAD
APRIL 1881
~ Scale of Feet ~
0
1250
2500
5000
7500
PENN R.R. FERRY
CENTRAL R.R. OF N JERSEY FERRY
CITY HALL PARK
FULTON FY
WALL ST. FY
BUTTERMILK CHANNEL
ATLANTIC BASIN
ERIE BASIN
BROOKLYN BASIN
GOWANUS BAY

HUDSON R
ELYSIAN F.
ERIE R.R. FERRY
TWELFTH AV.
ELEVENTH
TENTH
NINTH
EIGHTH
SEVENTH
SIXTH
FIFTH
MADISON
FOURTH
LEXINGTON
THIRD
SECOND
FIRST
AV.
EAST RIVER
GREEN POINT FERRY
GRAND ST. FERRY
U.S. NAVY YARD
NEWTOWN CREEK



STATIONS

2d AVE.	3d AVE.	6th AVE.	9th AVE.
So. Ferry	City Hall	Rector St.	So. Ferry
Hanover Sq.	Chatham Sq.	Cortlandt St.	Rector St.
Fulton St.	Canal St.	Park Place	Cortlandt St.
Franklin Sq.	Grand -	Chambers St.	Barclay -
Chatham -	Houston -	Franklin -	Warren -
Canal St.	9th St. & 3d Ave.	Grand -	Franklin -
Grand -	14th -	Bleecker -	Desbrosses -
Rivington St.	18th -	8th St. & 6th Ave.	Houston -
1st St. & 1st Ave.	23d -	14th -	Christopher -
8th -	28th -	23d -	14th St. & 9th Ave.
14th -	34th -	33d -	23d -
19th -	42d -	42d -	30th -
23d Street	47th -	50th -	34th -
34th St. & 2d Ave.	53d -	58th -	42d -
42d -	59th -	8th Ave. & 53d St.	50th -
50th -	67th -	59th St. & 9th Ave.	59th -
57th -	76th -	72d -	
65th -	84th -	81st -	
75th -	89th -	93d -	
86th -	98th -	104th -	
111th -	106th -	116th -	
120th -	116th -	125th - & 8th Ave.	
127th -	125th -	135th -	
Branches	129th -	145th -	
4th Ave. & 42d St.		155th -	
Ave. "A" & 34th -			

PLATE VIII.
TRANS. AM. SOC. CIV. ENG'RS
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HALL ON ELEVATED RAILROAD